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THE EFFECT OF DIAMETER ON THE
EFFORT REQUIRED TO ROTATE
HANDWHEELS USED AS CRANKS

A Thesis

Submitted to the Faculty
of

Purdue University

by

Herbert T. Fichman

In Partial Fulfillment of the
Requirements for the Degree

of

Master of Science in Industrial Engineering

June, 1932

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Appreciation and thanks are also expressed to William Terbo, Joseph Nestory, Hakon Refsum, John Crosse, Hans Coster, Elmo Lindquist and Marvin Adelberg for their loyal and enthusiastic performance as subjects for this thesis.

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ABSTRACT

The widespread use of handwheels in industry for the primary control of a wide variety of machine tools makes the proper design of these wheels a matter of importance. This experiment, designed to provide basic useful data in connection with this problem, was performed in the Motion and Time Study Laboratory at Purdue University.

Five handwheels ranging in diameter from four to fourteen inches were used by eight operators to overcome seven frictional torques ranging from three to sixty inch-pounds. The torques were applied by means of a prony brake. The rate of oxygen consumption by the operators was measured by a Sanborn EIS Metabolism Tester, and these measurements were used as the basic data from which the conclusions of the experiment were formulated.

Analysis of the data indicated that, within the limits of the ranges of the handwheel sizes and frictional torques used, the rate of human energy expenditure decreases with increased diameter of the handwheels.

The statistical analysis of the data indicated that the use of the Sanborn EIS Metabolism Tester is a satisfactory method for measuring human energy expenditure at relatively high levels.

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and the rate of output was about the same as

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The following is a list of the names of the persons who have been identified as having been in contact with the subject of this investigation during the period from January 1, 1964, to January 1, 1965.

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ANNEX 1

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1. The first part of the report is devoted to a general description of the situation in the country.
2. The second part is devoted to a description of the situation in the various regions of the country.
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5. The fifth part is devoted to a description of the situation in the various hamlets of the country.
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11. The eleventh part is devoted to a description of the situation in the various counties of the country.
12. The twelfth part is devoted to a description of the situation in the various shires of the country.
13. The thirteenth part is devoted to a description of the situation in the various hundreds of the country.
14. The fourteenth part is devoted to a description of the situation in the various tithings of the country.
15. The fifteenth part is devoted to a description of the situation in the various parishes of the country.
16. The sixteenth part is devoted to a description of the situation in the various parsonages of the country.
17. The seventeenth part is devoted to a description of the situation in the various vicarages of the country.
18. The eighteenth part is devoted to a description of the situation in the various rectories of the country.
19. The nineteenth part is devoted to a description of the situation in the various deaneries of the country.
20. The twentieth part is devoted to a description of the situation in the various dioceses of the country.

The above is a general description of the situation in the country. It is not intended to be a detailed description of the situation in each of the various regions, districts, villages, hamlets, farms, estates, manors, lordships, baronies, counties, shires, hundreds, tithings, parishes, parsonages, vicarages, rectories, deaneries, and dioceses of the country. It is intended to be a general description of the situation in the country as a whole.

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THE EFFECT OF DIAMETER ON THE
EFFORT REQUIRED TO ROTATE
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CRANKS

INTRODUCTION

The proper design of any mechanical devices which are to be used manually must of necessity include consideration of many physical factors, some of the more important being size, weight, handle type and relative positioning with respect to the operator. The specification of the ultimate physical dimensions which the finished device will have is for the most part directly related to the use to which the device will be put. The criteria for successful performance are varied, and the extent to which the design is considered successful depends on which criterion or combination of criteria the designer feels is the most important to optimize. A brief list of some of the more important criteria would include cost, speed of operation, ease of operation, accuracy of operation, safety of operation, consistency of operation, force delivered, power delivered, etc. The ease of operation or effort required by the operator to rotate handwheels under various conditions of torque loading will be the main concern of this thesis. Consideration of the various physical factors involved in the design of handwheels will be limited solely to consideration of the proper diameter. To attempt to consider all

THE REPORT OF THE
COMMISSIONERS OF THE
LAND OFFICE
IN
1900

CONTENTS

The report deals with the various matters which
have been brought before the Commission since the
last report was published. It contains a full
and complete account of the work done during the
year, and also a summary of the results of the
various inquiries which have been made. The
Commissioners have to report on the progress of
the various schemes which have been adopted for
the improvement of the land, and on the results
of the various inquiries which have been made
into the various matters which have been brought
before them. They also have to report on the
various matters which have been brought before
them by the various bodies which have been
constituted for the purpose of dealing with
the various matters which have been brought
before them. The Commission has to report on
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which have been made into the various matters
which have been brought before them. They also
have to report on the various matters which
have been brought before them by the various
bodies which have been constituted for the
purpose of dealing with the various matters
which have been brought before them.

the factors would be outside the scope of one thesis.

In the past, little consideration has been given to the proper dimensioning of handwheels in spite of their widespread application on most types of machine tools. In many instances the handwheels used have been much too small to effectively overcome the torques applied and in many cases the wheels have been unnecessarily large. Little information is available as to proper handwheel diameters from the standpoint of energy expenditure on the part of the operator. The main reason for this has been the lack (until recent years) of a suitable method of measuring the amount of energy a person expends while performing a given task. Measurement of the work done in foot pounds does not give the answer, since much depends upon the manner in which the work is performed, the conditions under which it is performed, and the characteristics of the operator performing the work. A person may himself work extremely hard and yet accomplish a relatively small amount of work as measured on the output end.

The reduction of the effort required by an operator to perform a given task is of prime concern to both labor and management, since such reductions are reflected in lower costs and higher quantity of production. This becomes especially important when highly repetitive jobs are considered. A machine tool operator, tending several

machines simultaneously, manipulates the machine controls many times in the course of a normal working day. Decreasing the operator's energy expenditure is almost certain to increase his effectiveness.

As has been pointed out previously in this thesis, few methods are available for the absolute measurement of human energy expenditure. However, the measurement of body metabolism as a measure of human energy expenditure has been used with success in several previous investigations at Purdue University. Tilles established the fact that a standard medical metabolism tester will successfully discriminate between small changes in human energy output¹. The Sanborn EIS Metabolism Tester was used in this experiment to determine differences in energy requirements with respect to the diameter of several handwheels.

1. TILLES, SEYMOUR, "An Investigation of the Suitability of the Sanborn EIS Metabolism Tester to Basic Motion Study Experimentation", Master of Science Thesis, Purdue University, Lafayette, Indiana, 1949.

...the
... ..
... ..
... ..
... ..
... ..

It is not possible to determine the exact date of the first publication of the book, but it is known that it was published in the year 1844. The book is a valuable work, and it is one of the best of its kind. It is a book that is well worth reading, and it is one that is well worth the trouble of finding it. It is a book that is well worth the trouble of finding it, and it is one that is well worth the trouble of finding it.

EXPERIMENTAL PROCEDURE

Design of Method and Apparatus

Purpose

The primary purpose of this experiment is the determination of the optimum diameter handwheel for a given torque load applied to a shaft, when the handwheel is used as a crank. The secondary purpose is to determine the maximum torque which an operator may reasonably be expected to overcome with a given diameter handwheel. The tertiary purpose is to obtain information about the Sanborn Metabolism Tester which may be of value to other investigators in the field of basic motion study, and to prove its reliability for use in connection with the measurement of relatively high level energy expenditure.

Method

In order to facilitate the analysis of the data, as many conditions were held constant as was feasible. The height of the work area (i.e., the center of the pronny brake shaft) was held constant at forty-four inches from the floor. The plane of the handwheels was held constant at 0 degrees angle of inclination with the vertical. The ambient temperature was held constant at twenty-eight degrees Centigrade and the pace at which the operator worked was controlled as closely as possible to forty RPM.

Five handwheels at seven torque loads were

investigated so that each operator had a total of thirty-five tasks to perform. Doubtless the results of the experiment would have been of more value had it been possible to investigate a greater number of handwheels and a wider range of torques. Further, it was felt that the use of a larger number of subjects would have increased the reliability of the findings. However, both the number of operators and the number of conditions investigated were severely limited by the time required for gathering and processing the data.

There was no method available for determining the length of time that would be required for the physiological recovery for each operator from a test run. However, a pilot test run indicated that undue fatigue would not occur within the two hour time allotted for each group of test runs. Further, it was felt that since the experiment was designed as much as possible to coincide with conditions in industry where an operator works for much longer periods of time, any fatigue occurring would not have excessively adverse effects on the results. Behl found that an operator performing a simple task could be expected to work for approximately one hour before appreciable fatigue occurred². The total working time for an operator during each two hour session was approximately thirty-six minutes.

2. BEHL, JOHN, "Determination of the Effect of Performing a Simple Task Over a Prolonged Period on the Rate of Energy Expenditure", Master of Science Thesis, Purdue University, Lafayette, Indiana.

[illegible]

The effects of learning and operator skill were minimized as much as possible by completely randomizing the order in which each operator was presented with the different conditions of handwheels and torques. This had the desirable effect of eliminating any sequence effects which might creep in if a set pattern were developed. The following tables indicate the order in which the tasks were presented to each operator.

NOTE: In the tables which follow, each task is designated by two numbers separated by a dash. The first number indicates the hand-wheel diameter in inches. The second number indicates the applied torque in inch-pounds. Thus, for example, the number 5-40 indicates the 5-inch handwheel with 40 inch-pounds of applied torque.

The Bureau of Land Management has indicated to the Bureau of Reclamation that it is possible to develop a water storage project on the Colorado River at the mouth of the Colorado River. The project would consist of a dam and a reservoir. The dam would be located at the mouth of the Colorado River, and the reservoir would be located upstream from the dam. The project would provide a water storage capacity of 1,000,000 acre feet. The project would also provide a water storage capacity of 1,000,000 acre feet. The project would also provide a water storage capacity of 1,000,000 acre feet.

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count. The second is the number of words.
The third is the number of words. The fourth
indicates the word count in the original.
The fifth, the number of words. The sixth
the word count in the original.

Table 1
Operator Characteristics

<u>Operator</u>	<u>Age</u>	<u>Height</u>	<u>Weight</u>	<u>Nationality</u>
William Terbo	22	6'2"	160	American
Hans Coster	28	5'9-1/4"	176	Dutch
Joseph Nestory	23	5'10-1/2"	165	American
Herbert Fichman	31	5'11-1/4"	185	American
John Crosse	26	6'0"	165	British
Elmo Lindquist	39	5'10"	175	American
Marvin Adelberg	23	6'3"	195	American
Hakon Refsum	24	6'2"	190	Norwegian

Table 1

Geometric Parameters

Parameter	Value	Unit	Symbol
Radius of gyration	1.50	Å	R_g
End-to-end distance	1.75	Å	r_{ee}
Mean square end-to-end distance	1.50	Å ²	$\overline{r_{ee}^2}$
Mean square end-to-end distance per unit length	1.50	Å ² /Å	$\overline{r_{ee}^2}/l$
Mean square end-to-end distance per unit length per unit mass	1.50	Å ² /Å/g	$\overline{r_{ee}^2}/(lM)$
Mean square end-to-end distance per unit length per unit mass per unit temperature	1.50	Å ² /Å/g/°K	$\overline{r_{ee}^2}/(lMT)$
Mean square end-to-end distance per unit length per unit mass per unit temperature per unit solvent viscosity	1.50	Å ² /Å/g/°K/cP	$\overline{r_{ee}^2}/(lMT\eta)$
Mean square end-to-end distance per unit length per unit mass per unit temperature per unit solvent viscosity per unit solvent density	1.50	Å ² /Å/g/°K/cP/cm ³	$\overline{r_{ee}^2}/(lMT\eta\rho)$

Table 2

Sequence of Task Presentation to Operators

(Numbers within the table are tasks)

Operator:	<u>NESTORY</u>			<u>COSTER</u>		
Date:	18 <u>Mar.</u>	19 <u>Mar.</u>	23 <u>Mar.</u>	17 <u>Mar.</u>	20 <u>Mar.</u>	24 <u>Mar.</u>
	10-60	10-10	4-60	7-60	14-30	7-20
	7-3	10-30	10-40	7-10	5-3	4-50
	7-40	14-10	7-10	5-50	4-40	10-3
	5-10	10-50	10-20	4-10	14-10	10-60
	14-20	10-3	14-3	14-40	14-3	5-10
	5-50	7-30	5-3	5-60	4-30	10-20
	14-60	5-60	14-50	10-50	4-50	4-30
	4-10	7-60	14-40	7-30	14-60	10-10
	5-30	4-50	14-30	14-20	10-40	10-30
	4-3	5-40	4-30	4-60	5-40	5-30
	4-20	7-30	4-40	14-30	7-3	4-20
	5-20	7-20		7-40	5-20	

Operator:	<u>TERBO</u>			<u>FICHMAN</u>		
Date:	15 <u>Mar.</u>	16 <u>Mar.</u>	17 <u>Mar.</u>	3 <u>Apr.</u>	5 <u>Apr.</u>	6 <u>Apr.</u>
	5-50	4-60	4-30	4-30	10-10	4-60
	4-20	7-30	14-20	5-3	4-10	4-3
	14-10	10-20	14-60	4-40	5-40	10-30
	7-40	10-60	5-30	14-50	10-40	7-20
	7-60	14-3	5-60	5-20	14-30	7-30
	10-3	7-10	14-40	10-50	7-3	10-3
	7-20	4-10	10-10	5-60	5-10	7-60
	7-30	7-3	10-50	14-40	7-10	7-40
	10-30	15-30	5-20	5-30	14-3	14-10
	4-30	10-40	14-50	14-60	10-60	4-20
		5-40	4-40	14-20	10-20	5-50
		4-10	4-50	4-30	7-50	
			5-3			

Comparison of the results of the two methods
(the results of the two methods are compared)

Method 1			Method 2		
Year	1990	2000	Year	1990	2000
1990	1.0000	1.0000	1990	1.0000	1.0000
1991	1.0000	1.0000	1991	1.0000	1.0000
1992	1.0000	1.0000	1992	1.0000	1.0000
1993	1.0000	1.0000	1993	1.0000	1.0000
1994	1.0000	1.0000	1994	1.0000	1.0000
1995	1.0000	1.0000	1995	1.0000	1.0000
1996	1.0000	1.0000	1996	1.0000	1.0000
1997	1.0000	1.0000	1997	1.0000	1.0000
1998	1.0000	1.0000	1998	1.0000	1.0000
1999	1.0000	1.0000	1999	1.0000	1.0000
2000	1.0000	1.0000	2000	1.0000	1.0000

Table 2 (Continued)

Sequence of Task Presentation to Operators

(Numbers within the table are tasks)

Operator:	<u>CROSBIE</u>			<u>LINDQUIST</u>		
Date:	<u>1</u>	<u>2</u>	<u>4</u>	<u>7</u>	<u>8</u>	<u>9</u>
	<u>Apr.</u>	<u>Apr.</u>	<u>Apr.</u>	<u>Apr.</u>	<u>Apr.</u>	<u>Apr.</u>
	4-3	4-10	4-20	10-10	7-40	4-20
	14-60	7-50	10-60	7-3	14-50	5-30
	4-60	4-30	10-30	5-40	4-60	10-30
	14-30	4-60	5-50	10-40	14-20	10-10
	5-10	14-10	7-30	14-60	7-30	4-3
	14-40	5-40	4-40	7-50	10-50	10-20
	5-30	10-10	10-3	4-3	5-60	4-10
	7-40	10-20	7-30	14-3	14-40	10-60
	4-50	10-40	14-3	3-20	4-10	10-3
	10-50	5-20	7-20	4-40	5-50	4-50
	5-3	7-3	14-50	5-3	7-10	7-20
	14-20		7-10	14-30	7-50	

Operator:	<u>REFSUM</u>			<u>ADELBURG</u>		
Date:	<u>3</u>	<u>10</u>	<u>11</u>	<u>29</u>	<u>9</u>	<u>10</u>
	<u>Apr.</u>	<u>Apr.</u>	<u>Apr.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>Apr.</u>
	4-20	7-3	14-50	14-3	5-20	4-3
	10-30	5-40	4-60	10-30	4-30	4-60
	5-30	14-60	14-20	10-3	7-50	14-60
	10-10	7-50	10-50	7-30	5-60	14-30
	4-3	4-30	5-60	5-50	10-20	5-10
	10-20	14-3	5-50	7-20	4-10	14-40
	5-10	14-10	14-40	7-60	14-10	5-30
	10-60	4-40	4-10	7-10	5-40	7-40
	4-50	5-3	5-50	10-60	10-40	10-50
	7-20	14-30	7-10	4-20	7-3	4-50
	10-3	10-40	7-60	4-40	10-10	5-3
	5-20	7-40	7-30	14-50		14-20

Year	1990	1991	1992	1993	1994	1995
1990	100	100	100	100	100	100
1991	100	100	100	100	100	100
1992	100	100	100	100	100	100
1993	100	100	100	100	100	100
1994	100	100	100	100	100	100
1995	100	100	100	100	100	100

Task

The tasks used consisted of cranking a handwheel mounted on the shaft of a prony brake. The speed used for all tasks was 40 RPM. The operator cranked from the standing position at a comfortable distance from the apparatus as shown in Figure 2. The distance from the apparatus at which the operator stood was left to the discretion of the operator. The operator cranked with his right hand and steadied himself by holding onto the left vertical upright of the prony brake with his left hand. Upon receipt of a verbal signal the operator began cranking and continued for three minutes, making one revolution for each two beats of a metronome set to oscillate at 80 beats per minute. The operator stopped cranking upon a second verbal signal. Upon completion of the task, the operator rested in a chair for five minutes while the handwheel and the torque were being changed for the next test run.

Each operator was given a total of thirty-five tasks, performed over a period of three separate days. These tasks covered every possible combination of handwheels and torques. Thorson found that there are no significant differences in oxygen consumption rates between identical tasks performed on different days³. From this it may be logically concluded that

3. Thorson, P. J., "A Metabolic Investigation of One-Handed Versus Two-Handed Work", Master of Science Thesis, Purdue University, Lafayette, Indiana, August, 1951.

ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED

10-10-68

shown in Figure 5. The average loss for sorption at 100°C

the present study was not designed to test the null hypothesis of no difference in the two groups.

[illegible]

1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 26

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1. NAME _____

Source: *The New York Times*, 1967.

the differences between unlike tasks performed on different days should be constant. This constitutes the justification for spreading the tasks over three separate days.

Test Procedure

The tests were run in the metabolic room of the Motion and Time Study Laboratory at Purdue University. It was possible to bar this room from all persons with the exception of the operator and the writer. This was done in order to reduce the effect of random outside influences on the operator.

Prior to the first test run, each operator was completely briefed on the purpose of the experiment, the function of the prony brake, the function of the metabolism tester and the function of the metronome. Every precaution was taken to alleviate the nervousness induced by the metabolism tester. Following the briefing, the operator was given a trial test run in order to insure the complete understanding of the test procedure. All tests on all operators were governed by the following basic time schedule which was begun upon the arrival of the operator for the experiment.

<u>Step</u>	<u>Time</u>	<u>Elapsed Time</u>	<u>Action</u>
1	0-15	15 min.	Operator rested on cot. Just prior to the end of 15 minute period, the operator took a standing position facing the test apparatus. The nose clamp was adjusted and the rubber hose mouth piece was inserted in the operator's mouth.

<u>Step</u>	<u>Time</u>	<u>Elapsed Time</u>	<u>Action</u>
2	15-17	2 min.	The operator stood quietly breathing ambient air through the metabolism tester.
3	17-21	4 min.	The oxygen was turned on without the operator's knowledge and the operator began to breathe pure oxygen. This step constituted the basal or no work run. At the conclusion of this run, the operator was disassembled from the metabolic equipment and seated in a chair.
4	21-25	4 min.	Operator rested quietly in chair. Just prior to the end of the 4 minute rest period, the operator again took his position in front of the work area and was assembled to the metabolic equipment as in step 1 above.
5	25-26	1 min.	Operator stood quietly breathing ambient air through the metabolator.
6	26-27	1 min.	Operator began cranking the hand-wheel in time with the metronome while breathing ambient air through the metabolator. This constituted the warm-up period.
7	27-29	2 min.	Without the knowledge of the operator, the oxygen was turned on and the operator began breathing pure oxygen while continuing to crank in time with the metronome. At the conclusion of the two minute work period, the equipment was turned off and the operator disassembled from the apparatus and seated in the chair to rest.
8	29-34	5 min.	The operator rested in chair for five minutes while the handwheel and torque were being changed.

Page	Date	Time	Subject
1	10-17	10:00	...
2	10-17	10:00	...
3	10-17	10:00	...
4	10-17	10:00	...
5	10-17	10:00	...
6	10-17	10:00	...
7	10-17	10:00	...
8	10-17	10:00	...
9	10-17	10:00	...

Steps 3 through 8 above, constituted a complete work-rest cycle of 9 minutes, of which 3 minutes were spent working and 6 minutes were spent resting. This work-rest cycle was repeated 12 times for each session in the lab. Following the completion of the final work-rest cycle, a second at rest basal test was run. Each complete session took about two hours and twenty minutes to complete and resulted in two basal tests and twelve working tests.

The selection of one minute for a warm-up period was based on the research of Behl, who showed that for a simple task, energy expenditure rises rapidly during the first minute of performance and does not change significantly for the next 64 minutes⁴.

Equipment

1. The Sanborn EIS Metabolism Tester, shown in Figure 3, had the following essential elements:

- a. A synchronous motor which rotated the metal cylinder upon which the wax data chart was mounted.
- b. A spirometer bell which contained pure oxygen to be consumed by the operator.
- c. A metal pointer which inscribed the movement of the spirometer bell upon the wax chart.

4. BEHL, JOHN, "Determination of the Effect of Performing a Simple Task Over a Prolonged Period on the Rate of Energy Expenditure", Master of Science Thesis, Purdue University, Lafayette, Indiana, 1950.

... 3 minutes 30 seconds, consisting of 3 minutes
rest-stand, 3 minutes of 3 minutes, at which 3 minutes rest-stand
working and 3 minutes rest-stand. This rest-stand
again was repeated 12 times the same manner in the last.
Following the completion of the final rest-stand, a
record of your heart beat was run. This complete session
took about two hours and twenty minutes to complete and was
valued in two heart beats and twelve working beats.
The selection of the subject for a one-up game
was based on the results of the 12 minutes rest-stand
single back, every organization then took the
three minutes of performance and some had enough energy
to play for the next 30 minutes.

Summary

1. The subject was instructed to rest, when in place.
2. The following results were obtained:
a. A questionnaire which was filled out the last time
and upon which the test data was based.
b. A questionnaire which was filled out the last time
and upon which the test data was based.
c. A questionnaire which was filled out the last time
and upon which the test data was based.
d. A questionnaire which was filled out the last time
and upon which the test data was based.
e. A questionnaire which was filled out the last time
and upon which the test data was based.
f. A questionnaire which was filled out the last time
and upon which the test data was based.
g. A questionnaire which was filled out the last time
and upon which the test data was based.
h. A questionnaire which was filled out the last time
and upon which the test data was based.
i. A questionnaire which was filled out the last time
and upon which the test data was based.
j. A questionnaire which was filled out the last time
and upon which the test data was based.
k. A questionnaire which was filled out the last time
and upon which the test data was based.
l. A questionnaire which was filled out the last time
and upon which the test data was based.
m. A questionnaire which was filled out the last time
and upon which the test data was based.
n. A questionnaire which was filled out the last time
and upon which the test data was based.
o. A questionnaire which was filled out the last time
and upon which the test data was based.
p. A questionnaire which was filled out the last time
and upon which the test data was based.
q. A questionnaire which was filled out the last time
and upon which the test data was based.
r. A questionnaire which was filled out the last time
and upon which the test data was based.
s. A questionnaire which was filled out the last time
and upon which the test data was based.
t. A questionnaire which was filled out the last time
and upon which the test data was based.
u. A questionnaire which was filled out the last time
and upon which the test data was based.
v. A questionnaire which was filled out the last time
and upon which the test data was based.
w. A questionnaire which was filled out the last time
and upon which the test data was based.
x. A questionnaire which was filled out the last time
and upon which the test data was based.
y. A questionnaire which was filled out the last time
and upon which the test data was based.
z. A questionnaire which was filled out the last time
and upon which the test data was based.

- d. A two-way valve, whose function was the selection of either pure oxygen or ambient air for the operator's consumption.
- e. A metaboline container, located inside the spirometer bell housing, had the function of filtering out the waste products of respiration, namely carbon dioxide and water vapor.
- f. Nose clamp and rubber mouth piece whose function was the elimination of the possibility of ambient air entering the closed system formed by the operator and the metabolinometer.

2. The required frictional torques were obtained by means of prony brake especially designed for this experiment, and containing the following essential features: (See Figure 4)

- a. A wooden frame constructed of 2" x 4" planks, 47 inches high by 20 inches wide.
- b. A Sears and Roebuck Co. "Craftsman" 3/4 inch steel shaft and bearing mounts.
- c. A maple wood wheel 3 inches thick with a radius of 2.573 inches. This wheel was mounted upon the steel shaft by means of two flanges containing 1/4 inch set screws.
- d. Two Chantillon spring balances of 100 pound capacity, whose function was the rapid indication of the required frictional torque.

4. A further valve, whose function was the admission of either fresh oxygen or ambient air to the oxygenator's atmosphere.

5. A mechanical controller, located inside the oxygenator bell housing, had the function of lifting the two waste products of respiration, namely carbon dioxide and water vapor.

6. Two glass and rubber hoses, whose function was the elimination of the possibility of ambient air entering the closed system formed by the oxygenator and the mechanical controller.

7. The required electrical system was obtained by means of three electrically isolated low voltage sources and containing the following essential features: (see figure 1)

a. A wooden frame constructed of 2" x 4" slats, 47 inches high by 24 inches wide.

b. A large and heavy-duty "Universal" 2 1/2 inch wheel with a heavy metal mounting.

c. A single wheel 5 inches wide with a rubber tire. This wheel was mounted with the steel base of the frame of the oxygenator.

d. A 1/2 inch steel wheel.

8. The mechanical spring balance of 100 grams was used, whose function was the rapid indication of the required electrical output.

- e. Two aluminum turnbuckles whose function was the rapid adjustment of the required frictional torque.
- f. One nylon belt, 1-3/4 inches wide by 24 inches long, which, in conjunction with the polished wooden wheel, formed the friction element of the prony brake. A calibration curve for the prony brake appears in Appendix A.

3. The five cast iron handwheels which were investigated (See Figure 5) were standard industrial handwheels, and had the following characteristics:

Number	Diameter	Weight
1	4 inches	1.50 pounds
2	5 inches	2.00 pounds
3	7 inches	4.70 pounds
4	10 inches	10.00 pounds
5	14 inches	21.50 pounds

4. One Metronome De Maazel performed the function of pace indication for the operator (See Figure 4).

7. The kinetic properties were determined for the
weight adjustment of the polymerization

series.

8. The other half, 1-2/3 inches wide by 12 inches
long, which, in section, is 1/2 inch thick
wooden shell, formed the kinetic element of the
group series. A calibration curve for the group
series appears in Appendix A.

9. The five runs from 1000 to 1500 were investigated
(see Figure 2) were checked for kinetic properties, and had
the following characteristics:

Weight	Temperature	Number
1.50 pounds	2 inches	1
2.00 pounds	2 inches	2
2.50 pounds	2 inches	3
3.00 pounds	2 inches	4
3.50 pounds	2 inches	5

10. The difference in kinetic properties and location of

the reaction for the series (see Figure 2).

RESULTS AND CONCLUSIONS

Calculations

The basic data upon which the conclusions of this experiment were formulated were derived from the wax charts of the metabolism tester. The wax charts were wrapped around the metal cylinder which was driven at constant speed by the synchronous motor. The abscissa of the charts were the measure of elapsed time. As the operator inhaled, pure oxygen was breathed in from the spirometer bell causing the spirometer bell to fall. As the operator exhaled, the spirometer bell rose. This alternate rising and falling of the bell produced the peaked line on the wax chart. As each exhalation of the operator passed into the spirometer bell, the products of respiration were filtered out by the metabolism. Thus the spirometer bell rose to successively lower positions following each exhalation. This was indicated on the wax chart by successively lower peaks and was a measure of the rate at which the oxygen was being removed from the spirometer bell, and consequently a measure of the rate of oxygen consumption or energy expenditure by the operator.

Had the operator consumed oxygen at an absolutely constant rate, a straight line could have been passed through the successive peaks of the saw toothed graph on the chart. The slope of this line would measure the rate of oxygen consumption in cubic centimeters per minute. However, due to

the difference in volume of the operator's successive breaths, the respiratory cycle was not constant and the peaks did not fall into a straight line. It was therefore necessary to make the best possible approximation to a straight line by the method of least squares. A sample calculation of this method is shown in Appendix A, along with the steps necessary to convert the slope value to cubic centimeters of oxygen per minute. For the purpose of this thesis, it was not necessary to calculate the actual oxygen volume consumption since analysis of the slopes directly gave the required comparative information. In this connection, Wood has shown that corrections for temperature and pressure would be too small to have appreciable effect on the results, and therefore these corrections were not made⁵. The raw data for this thesis are deposited in the Motion and Time Laboratory at Purdue University.

5. WOOD, J. F., "The Determination by Means of Metabolic Measurements of the Time Allowances to be Included Within Standard Rates for Jobs Partially Controlled by Machines", Master of Science Thesis, Purdue University, Lafayette, Indiana, 1951.

Table 3a.

SLOPE VALUES FOR EACH HANDWHEEL

DIAMETER

Torque = 3 inch pounds

Operator's Name	<u>4 inch</u>	<u>5 inch</u>	<u>7 inch</u>	<u>10 inch</u>	<u>14 inch</u>
TERBO	.419	.458	.471	.435	.505
COSTER	.288	.418	.337	.239	.318
HASTORY	.334	.330	.337	.392	.336
FICKMAN	.405	.391	.400	.495	.453
CROSSE	.487	.462	.451	.390	.382
LINDQUIST	.358	.432	.422	.346	.407
ADELBERG	.479	.449	.443	.643	.616
REFSUM	<u>.606</u>	<u>.549</u>	<u>.485</u>	<u>.575</u>	<u>.535</u>
MEAN	.420	.436	.418	.439	.442
95% Conf. Limit of Mean	$\pm .083$	$\pm .053$	$\pm .047$	$\pm .107$	$\pm .088$

2008 年 4 月 20 日

Station	1st	2nd	3rd	4th	5th
1000	1000	1000	1000	1000	1000
900	900	900	900	900	900
800	800	800	800	800	800
700	700	700	700	700	700
600	600	600	600	600	600
500	500	500	500	500	500
400	400	400	400	400	400
300	300	300	300	300	300
200	200	200	200	200	200
100	100	100	100	100	100

Table 3b.

SLOPE VALUES FOR EACH HANDWHEEL

DIAMETER

Torque = 10 inch pounds

Operator's Name	<u>4 inch</u>	<u>5 inch</u>	<u>7 inch</u>	<u>10 inch</u>	<u>14 inch</u>
TERBO	.647	.536	.607	.499	.383
COSTER	.464	.530	.667	.495	.401
NESTORY	.500	.452	.432	.354	.396
FIGMAN	.803	.499	.606	.819	.575
CROSSE	.673	.606	.435	.543	.440
LINDQUIST	.744	.513	.634	.527	.477
ADIELBERG	.818	.637	.496	.475	.620
REFSUM	<u>.748</u>	<u>.692</u>	<u>.622</u>	<u>.697</u>	<u>.581</u>
MEAN	.675	.581	.562	.551	.484
95% Conf. Limits of Mean	$\pm .110$	$\pm .069$	$\pm .076$	$\pm .119$	$\pm .072$

[illegible]

Table 3c.
SLOPE VALUES FOR EACH HANDWHEEL
DIAMETER

Torque = 20 inch pounds

<u>Operator's Name</u>	<u>4 inch</u>	<u>5 inch</u>	<u>7 inch</u>	<u>10 inch</u>	<u>14 inch</u>
TERBO	.781	.895	.812	.624	.611
COSTER	1.099	.620	.787	.640	.509
NESTORY	.803	1.011	.536	.688	.448
FICHMAN	.977	.940	.553	.429	.635
CROSSE	.770	.848	.606	.587	.507
LINDQUIST	.816	.836	.596	.548	.606
ADELBERG	.992	.804	.849	.731	.591
REFJUN	<u>2.186</u>	<u>.998</u>	<u>.647</u>	<u>.781</u>	<u>.752</u>
MEAN	1.053	.869	.673	.629	.532
95% Conf. Limit of Mean	$\pm .390$	$\pm .105$	$\pm .103$	$\pm .092$	$\pm .079$

TABLE 50.
 GRADE PRICES FOR GRAIN
 MARKET
 GRAIN & GRAIN PRODUCTS

1913	1914	1915	1916	1917	1918
110.	112.	114.	116.	118.	120.
120.	122.	124.	126.	128.	130.
130.	132.	134.	136.	138.	140.
140.	142.	144.	146.	148.	150.
150.	152.	154.	156.	158.	160.
160.	162.	164.	166.	168.	170.
170.	172.	174.	176.	178.	180.
180.	182.	184.	186.	188.	190.
190.	192.	194.	196.	198.	200.
200.	202.	204.	206.	208.	210.
210.	212.	214.	216.	218.	220.
220.	222.	224.	226.	228.	230.
230.	232.	234.	236.	238.	240.
240.	242.	244.	246.	248.	250.
250.	252.	254.	256.	258.	260.
260.	262.	264.	266.	268.	270.
270.	272.	274.	276.	278.	280.
280.	282.	284.	286.	288.	290.
290.	292.	294.	296.	298.	300.
300.	302.	304.	306.	308.	310.
310.	312.	314.	316.	318.	320.
320.	322.	324.	326.	328.	330.
330.	332.	334.	336.	338.	340.
340.	342.	344.	346.	348.	350.
350.	352.	354.	356.	358.	360.
360.	362.	364.	366.	368.	370.
370.	372.	374.	376.	378.	380.
380.	382.	384.	386.	388.	390.
390.	392.	394.	396.	398.	400.
400.	402.	404.	406.	408.	410.
410.	412.	414.	416.	418.	420.
420.	422.	424.	426.	428.	430.
430.	432.	434.	436.	438.	440.
440.	442.	444.	446.	448.	450.
450.	452.	454.	456.	458.	460.
460.	462.	464.	466.	468.	470.
470.	472.	474.	476.	478.	480.
480.	482.	484.	486.	488.	490.
490.	492.	494.	496.	498.	500.
500.	502.	504.	506.	508.	510.
510.	512.	514.	516.	518.	520.
520.	522.	524.	526.	528.	530.
530.	532.	534.	536.	538.	540.
540.	542.	544.	546.	548.	550.
550.	552.	554.	556.	558.	560.
560.	562.	564.	566.	568.	570.
570.	572.	574.	576.	578.	580.
580.	582.	584.	586.	588.	590.
590.	592.	594.	596.	598.	600.
600.	602.	604.	606.	608.	610.
610.	612.	614.	616.	618.	620.
620.	622.	624.	626.	628.	630.
630.	632.	634.	636.	638.	640.
640.	642.	644.	646.	648.	650.
650.	652.	654.	656.	658.	660.
660.	662.	664.	666.	668.	670.
670.	672.	674.	676.	678.	680.
680.	682.	684.	686.	688.	690.
690.	692.	694.	696.	698.	700.
700.	702.	704.	706.	708.	710.
710.	712.	714.	716.	718.	720.
720.	722.	724.	726.	728.	730.
730.	732.	734.	736.	738.	740.
740.	742.	744.	746.	748.	750.
750.	752.	754.	756.	758.	760.
760.	762.	764.	766.	768.	770.
770.	772.	774.	776.	778.	780.
780.	782.	784.	786.	788.	790.
790.	792.	794.	796.	798.	800.
800.	802.	804.	806.	808.	810.
810.	812.	814.	816.	818.	820.
820.	822.	824.	826.	828.	830.
830.	832.	834.	836.	838.	840.
840.	842.	844.	846.	848.	850.
850.	852.	854.	856.	858.	860.
860.	862.	864.	866.	868.	870.
870.	872.	874.	876.	878.	880.
880.	882.	884.	886.	888.	890.
890.	892.	894.	896.	898.	900.
900.	902.	904.	906.	908.	910.
910.	912.	914.	916.	918.	920.
920.	922.	924.	926.	928.	930.
930.	932.	934.	936.	938.	940.
940.	942.	944.	946.	948.	950.
950.	952.	954.	956.	958.	960.
960.	962.	964.	966.	968.	970.
970.	972.	974.	976.	978.	980.
980.	982.	984.	986.	988.	990.
990.	992.	994.	996.	998.	1000.

Table 3d.

SLOPE VALUES FOR EACH HANDWHEEL

DIAMETER

Torque = 30 inch pounds

<u>Operator's Name</u>	<u>4 inch</u>	<u>5 inch</u>	<u>7 inch</u>	<u>10 inch</u>	<u>14 inch</u>
TERBO	----	1.246	1.012	1.040	.671
COSTER	----	1.491	1.144	.790	.848
NESTORY	----	.971	.692	.566	.487
FICHMAN	----	.948	.535	.623	.728
CROSSE	1.467	.977	.938	.557	.658
LINDQUIST	----	2.368	.643	.632	.726
ADELBERG	1.370	.879	1.037	.752	.704
REFSUM	<u>1.820</u>	<u>1.172</u>	<u>.910</u>	<u>.876</u>	<u>.873</u>
MEAN	1.552	1.269	.901	.730	.712
95% Conf. Limit of Mean	----	±.123	±.154	±.140	±.100

NOTE: Blanks in the table indicate tasks which the operators were physically unable to perform in a satisfactory manner.

[illegible]

NOTE: There is no data below this line.

Table 3e.
 SLOT & VALUES FOR EACH HANDWHEEL
 DIAMETER

Torque = 40 inch pounds

Operator's Name	4 inch	5 inch	7 inch	10 inch	14 inch
TERBO	----	1.340	.826	.753	.750
COSTER	----	1.372	1.564	1.088	.817
NESTORY	----	1.072	.753	.778	.698
FICHMAN	----	1.454	.743	.768	.611
CROSSE	----	1.406	1.007	.883	.633
LINDQUIST	----	1.020	1.050	.829	.825
ADELBERG	----	1.035	.924	.855	.643
REFSUM	----	<u>1.822</u>	<u>1.128</u>	<u>.904</u>	<u>.991</u>
MEAN	----	1.316	1.000	.857	.746
95% Conf. Limits of Mean	----	±.225	±.222	±.090	±.107

NOTE: Blanks in the table indicate tasks which the operators were physically unable to perform in a satisfactory manner.

Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	

Table 3f.

SLOPE VALUES FOR EACH HANDWHEEL

DIAMETER

Torque = 50 inch pounds

Operator's Name	4 inch	5 inch	7 inch	10 inch	14 inch
TERBO	----	----	.929	.754	.797
COSTER	----	----	1.545	1.017	.807
NESTORY	----	----	.890	.712	.632
FICHMAN	----	----	.920	.874	.728
GROSSER	----	----	1.304	.730	.736
LINDQUIST	----	----	1.065	1.043	.748
ADELBERG	----	----	1.038	.850	.832
REFSUM	----	----	<u>1.494</u>	<u>1.035</u>	<u>.684</u>
MEAN	----	----	1.156	.877	.771
95% Conf. Limit on Mean	----	----	±.215	±.117	±.064

NOTE: Blanks in the table indicate tasks which the operators were physically unable to perform in a satisfactory manner.

Table 3g.

SLOPE VALUES FOR EACH HANDWHEEL

DIAMETER

Torque = 60 inch pounds

Operator's Name	4 inch	5 inch	7 inch	10 inch	14 inch
TERBO	----	----	2.101	.971	.800
COSTER	----	----	1.389	1.046	.877
NESTORY	----	----	1.145	.858	.689
FICHMAN	----	----	1.211	.914	.730
CROSSE	----	----	1.413	.668	.897
LINDQUIST	----	----	1.093	.808	.805
ADELBARG	----	----	.992	.824	.807
REFJUM	----	----	<u>1.381</u>	<u>1.124</u>	<u>1.094</u>
MEAN	----	----	1.341	.902	.837
95% Conf. Limit of Mean	----	----	±.286	±.121	±.104

NOTE: Blanks in the table indicate tasks which the operators were physically unable to perform in a satisfactory manner.

Table 20.
 Cattle raised for beef purposes
 by county
 1909 = 100 pounds

County	1909	1910	1911	1912	1913
Adair	100	100	100	100	100
Alfalfa	100	100	100	100	100
Beaver	100	100	100	100	100
Big Horn	100	100	100	100	100
Blaine	100	100	100	100	100
Bozeman	100	100	100	100	100
Butte	100	100	100	100	100
Chouteau	100	100	100	100	100
Custer	100	100	100	100	100
Deer	100	100	100	100	100
Golden	100	100	100	100	100
Grant	100	100	100	100	100
Jefferson	100	100	100	100	100
Lincoln	100	100	100	100	100
Logan	100	100	100	100	100
Madison	100	100	100	100	100
Mineral	100	100	100	100	100
Missoula	100	100	100	100	100
Montana	100	100	100	100	100
Mullan	100	100	100	100	100
Neenah	100	100	100	100	100
North	100	100	100	100	100
Platte	100	100	100	100	100
Richmond	100	100	100	100	100
Salt Lake	100	100	100	100	100
Shoshone	100	100	100	100	100
Silver	100	100	100	100	100
Summit	100	100	100	100	100
Teton	100	100	100	100	100
Thompson	100	100	100	100	100
Valley	100	100	100	100	100
Washington	100	100	100	100	100
Yellowstone	100	100	100	100	100

Note: Figures in this table represent cattle raised for beef purposes only. Figures in parentheses indicate the number of head of cattle raised for other purposes.

Source: U.S. Census Bureau.

Table 4.
MEAN* SLOPE VALUES FOR ALL
TASKS

HANDWHEEL DIAMETERS

<u>Torques</u>	<u>4 inch</u>	<u>5 inch</u>	<u>7 inch</u>	<u>10 inch</u>	<u>14 inch</u>
3 in.lbs.	.420	.436	.418	.439	.442
10 in.lbs.	.675	.561	.562	.551	.492
20 in.lbs.	1.053	.869	.673	.629	.562
30 in.lbs.	----	1.269	.901	.730	.712
40 in.lbs.	----	1.316	1.000	.657	.746
50 in.lbs.	----	----	1.136	.877	.771
60 in.lbs.	----	----	1.341	.902	.937

*Each value in Table 4 is arrived at by taking the arithmetic average of the corresponding values for eight operators.

NOTE: Blanks in the table indicate tasks for which the operators were physically unable to perform in a satisfactory manner.

FORM F
APPROVED FOR USE IN
PURDUE UNIVERSITY



FIGURE 1 - TORQUE CURVES

Results

The data obtained for this experiment indicates that, with the exception of extremely small torque loads, the amount of energy expended cranking a handwheel decreases as the handwheel diameter is increased. However, the graphs of the data show a definite flattening out of the torque curves at the larger diameters. This would indicate that, for the torques investigated, the optimum diameter is approximately ten inches. Dr. Mundel and other investigators have indicated that the amount of energy expended by an operator depends to a large extent upon the muscle groups brought into use, the larger group requiring higher expenditure⁶. This phenomenon appears to be operative in this experiment. It would seem that the reduced energy expenditure resulting from the increasing mechanical advantage of the larger wheels (requiring reduced force application) gradually becomes balanced (and finally overcome) by the higher energy expenditure required by the use of the larger muscle groups of the upper arms, shoulder and torso. The gradual rise of the lowest torque curve added weight to this supposition.

The curves further indicate that handwheels smaller than 7 inches in diameter should not be used to overcome

6. MUNDEL, M. E., Motion and Time Study Principles and Practice, p. 154, Prentice-Hall, Inc., New York, 1950.

Results

The data obtained for this experiment indicated that, with the exception of extremely small values, the amount of energy expended in producing a particular movement on the hand-wheel diameter is independent. However, the weight of the limb shows a definite relationship out of the range covered by the larger diameter. This result indicates that, for the purposes investigated, the system diameter is approximately the same. It, weight and other investigators have indicated that the amount of energy expended by an operator depends on a large extent upon the weight of the limb. This is in line with the results reported in the literature.⁶ This relationship appears to be operative in this experiment. It would seem that the reduced energy expenditure resulting from the increased mechanical advantage of the larger wheel (resulting in reduced force application) gradually becomes constant (and finally overcome) by the linear energy expenditure required by the use of the larger wheel. It is to be noted that, in the use of the larger wheel, the weight of the limb is not a factor. The greatest value of the energy expended occurs when the weight is not a factor.

The system diameter indicated that the weight of the limb is a factor in determining the energy expended in this experiment.

6. HOLLAND, C. E., Weight and Limb Length, University of Illinois, 1924, 1925, 1926.

torques in excess of 20 inch pounds (for continuous or high frequency repetitive operation), since to do so results in a high level of fatigue upon the operator. This was dramatically demonstrated by the inability of the operators to complete the test runs, using the smaller wheels, when torques in excess of 20 inch pounds were imposed. It was noted that, for the torque range between 30 and 60 inch pounds, the rate of decrease of energy expenditure with increased wheel size becomes very small. These break points which occur at the 10 inch wheel indicate that little is gained by increasing the wheel size much above this point.

The analysis of variance of the data showed significance at the 1% level for both wheels, torques, and wheels X torques, indicating that there was small probability that differences in the data could have occurred by chance. The interactions of wheels X operators and torques X operators had no statistical significance at the 5% level. This indicates that these causative effects were negligible and in fact did not cause significant differences in the slope values. However, the F test showed that the differences between operators was of significance at the 1% level of confidence. This was to be expected and could have been caused by any or all of several factors, some of the more probable being size, strength, rate of breathing, mental attitude and general condition of health of the operators.

The purpose of this study is to determine the effect of the use of the computer on the learning of the English language. The study was conducted in a classroom of 20 students. The students were divided into two groups. The first group used the computer for their English lessons, and the second group did not. The results of the study showed that the students who used the computer had a higher level of proficiency in English than the students who did not. This suggests that the use of the computer can be an effective tool for learning the English language.

No attempt was made to control the behavior of the subjects for the twenty-four hour period preceding the test. There is little reason to doubt that the activities of the subjects for the period preceding the tests had some effect on the data. Fortunately, this effect did not appear to be excessive and it is felt that it did little to impair the validity of the data.

The analysis of variance technique was used to evaluate the significance of the data⁷. The analysis was complicated by the fact that there were areas of missing data. It was found that the operators were physically incapable of cranking the 4 inch diameter handwheel for the required time interval, and at the required pace for torque loadings in excess of 20 inch pounds. A similar restriction was imposed on the use of the 5 inch diameter handwheel for torques in excess of 40 inch pounds. These areas of missing data precluded an analysis of the data as a whole. To solve this problem, the data was divided into two separate groups and an analysis of variance was conducted on each group. Group I data comprised all the slope values for torques 3, 10 and 20 inch pounds using all eight operators and all five handwheels. Group II data comprised the slope values for all seven torques, using all eight operators and handwheels of

7. LINDQUIST, E. F., Statistical Analysis in Educational Research, pp. 106-109, Houghton Mifflin Co., Boston, New York, Chicago, Atlanta, Dallas, San Francisco, 1940.

diameters 7, 10 and 14 inches respectively. The complete analysis of variance is indicated in Appendix A. The slope values are indicated in Tables 3a through 3g.

The 95% confidence limits for the means of the eight operators on each task were calculated using Student's t. These confidence limits are indicated in Tables 3a through 3g.

Conclusions

It may be concluded from this experiment that, to overcome torques in the range investigated, and with operator energy expenditure as the criterion, the larger diameter handwheels are more desirable.

For the torque range between 30 and 60 inch pounds the optimum diameter is at least ten inches.

For torques in excess of 20 inch pounds, handwheels of smaller diameter than seven inches are unsuitable.

It may be further concluded that the Sanborn EIS Metabolism Tester is a suitable device for making measurements of human energy expenditure at relatively high levels of performance.

Diagram V, is not a linear representation. The weights
assigned to vertices in Diagram V are indicated in Figure 2. The edges
weights are indicated in Figure 2. Diagram V.

The 200 vertices limit for the series of the
edge weights on each side were indicated with Figure 2.
These vertices limit are indicated in Figure 2. Diagram V.

Conclusion

It may be concluded from this experiment that, 70

vertices weights in the series is indicated, and with Figure 2.

weight assigned to the vertices, the larger the weight

assigned to the vertices, the larger the weight.

For the 200 vertices weights between 70 and 80 vertices

the weight assigned is at least 70 vertices.

For weights in between 70 and 80 vertices, 70-

weights of vertices assigned also have between 70 and 80 vertices.

It may be further concluded that the weights of

vertices assigned is a variable factor for weights assigned.

There is a linear relationship of vertices assigned to

the performance.



FIGURE 2

the following is a list of the names of the persons who have been elected to the office of the President of the United States since the year 1789.



The following is a list of the names of the persons who have been elected to the office of the President of the United States since the year 1789.

1789	George Washington
1793	Thomas Jefferson
1797	John Adams
1801	Thomas Jefferson
1805	James Madison
1809	James Monroe
1817	James Monroe
1821	James Monroe
1825	James Monroe
1829	Andrew Jackson
1833	Andrew Jackson
1837	Andrew Jackson
1841	Andrew Jackson
1845	Andrew Jackson
1849	Andrew Jackson
1853	Andrew Jackson
1857	Andrew Jackson
1861	Andrew Jackson
1865	Andrew Jackson
1869	Andrew Jackson
1873	Andrew Jackson
1877	Andrew Jackson
1881	Andrew Jackson
1885	Andrew Jackson
1889	Andrew Jackson
1893	Andrew Jackson
1897	Andrew Jackson
1901	Andrew Jackson
1905	Andrew Jackson
1909	Andrew Jackson
1913	Andrew Jackson
1917	Andrew Jackson
1921	Andrew Jackson
1925	Andrew Jackson
1929	Andrew Jackson
1933	Andrew Jackson
1937	Andrew Jackson
1941	Andrew Jackson
1945	Andrew Jackson
1949	Andrew Jackson
1953	Andrew Jackson
1957	Andrew Jackson
1961	Andrew Jackson
1965	Andrew Jackson
1969	Andrew Jackson
1973	Andrew Jackson
1977	Andrew Jackson
1981	Andrew Jackson
1985	Andrew Jackson
1989	Andrew Jackson
1993	Andrew Jackson
1997	Andrew Jackson
2001	Andrew Jackson
2005	Andrew Jackson
2009	Andrew Jackson
2013	Andrew Jackson
2017	Andrew Jackson
2021	Andrew Jackson



FIGURE 3

THE UNIVERSITY OF CHICAGO
 LIBRARY
 540 EAST 57TH STREET
 CHICAGO, ILL. 60637



120 E

120 E



FIGURE 4

THE [illegible] OF [illegible]





FIGURE 5



APPENDIX A

A. K. K. K.

A. K. K. K.

Discussion

The original intention had been to use the basal tests as a ground level from which to calculate the per cent increase of oxygen consumption of each test run over the no work condition. This idea was discarded after inspection of the basal tests indicated that little reliance could be placed on their reliability. The basals not only varied widely between operators but there was evidence of large random variation within each operator. In addition, it was noted that in several instances the values for the basal tests were higher than some of the lower level tasks. This was especially true of several of the low torque runs on the smaller handwheels. There are two possible explanations for this phenomenon. First, Tilles has shown that the Sanborn Metabolator gives results of low significance for light tasks involving finger movements of two or three inches.⁸ Second, there is a definite possibility that an operator finds it more fatiguing to stand motionless for several minutes than to perform a very light task. To avoid introducing an additional possible source of error into the data, the basal tests were not used in the calculations. A sample wax chart and data sheet are included at the end of this appendix as an example of the calculations used for computing rate of oxygen consumption slopes.

8. TILLES, SEYMOUR, "An Investigation of the Suitability of the Sanborn M13 Metabolism Tester to Basic Motion Study Experimentation", Master of Science Thesis, Purdue University, Lafayette, Indiana, 1949.

Discussion

The statistical analysis has been in the hands of a group of people who have been able to make a comparison of each level for each of the various levels. This has been done in a way which is not only valid but also reliable. The results are given in the following table. It is noted that in several instances the values are the same. This is due to the fact that the same level of the same type of results is given in several instances. There are two possible explanations for this phenomenon. First, it is possible that the same level of results is given in several instances. This is due to the fact that the same level of the same type of results is given in several instances. Second, there is a definite possibility that the same level of results is given in several instances. This is due to the fact that the same level of the same type of results is given in several instances. It is noted that in several instances the values are the same. This is due to the fact that the same level of the same type of results is given in several instances. There are two possible explanations for this phenomenon. First, it is possible that the same level of results is given in several instances. This is due to the fact that the same level of the same type of results is given in several instances. Second, there is a definite possibility that the same level of results is given in several instances. This is due to the fact that the same level of the same type of results is given in several instances.

S. L. LILLY, JR., as Investigator of the Statistical
 the Bureau of Statistics, Bureau of Census, Washington, D.C.
 (Continued on next page)

A rectangular coordinate system was imposed upon the wax charts and the X and Y coordinates of each peak of the saw tooth graph recorded. The slope of the best straight line which could be approximated was obtained from the following formula:

$$b = \frac{\sum XY - N\bar{X}\bar{Y}}{(\sum X)^2 - N\bar{X}^2}$$

where b = slope of line on wax chart in inches per inch

N = the number of peaks of the saw toothed graph

X, Y = rectangular coordinates of the peaks of the saw toothed graph.

On the wax charts a line with a slope of 1.000 represents 854.5 cubic centimeters of oxygen per minute. Therefore, the volume of oxygen consumed per minute for a given task is readily calculated by multiplying the appropriate slope by 854.5.

$$\text{Cubic Cm. per minute} = b \times 854.5$$

A pointwise maximum exists and is unique. The set
 of all f and g satisfying (1) is denoted by \mathcal{F} .
 The set of all f and g satisfying (2) is denoted by \mathcal{G} .
 The set of all f and g satisfying (3) is denoted by \mathcal{H} .
 The set of all f and g satisfying (4) is denoted by \mathcal{I} .
 The set of all f and g satisfying (5) is denoted by \mathcal{J} .

$$f = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right)$$

The set of all f and g satisfying (6) is denoted by \mathcal{K} .
 The set of all f and g satisfying (7) is denoted by \mathcal{L} .
 The set of all f and g satisfying (8) is denoted by \mathcal{M} .
 The set of all f and g satisfying (9) is denoted by \mathcal{N} .
 The set of all f and g satisfying (10) is denoted by \mathcal{O} .

The set of all f and g satisfying (11) is denoted by \mathcal{P} .
 The set of all f and g satisfying (12) is denoted by \mathcal{Q} .
 The set of all f and g satisfying (13) is denoted by \mathcal{R} .
 The set of all f and g satisfying (14) is denoted by \mathcal{S} .
 The set of all f and g satisfying (15) is denoted by \mathcal{T} .

$$f = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right)$$

The set of all f and g satisfying (16) is denoted by \mathcal{U} .
 The set of all f and g satisfying (17) is denoted by \mathcal{V} .
 The set of all f and g satisfying (18) is denoted by \mathcal{W} .
 The set of all f and g satisfying (19) is denoted by \mathcal{X} .
 The set of all f and g satisfying (20) is denoted by \mathcal{Y} .

The set of all f and g satisfying (21) is denoted by \mathcal{Z} .
 The set of all f and g satisfying (22) is denoted by \mathcal{A} .
 The set of all f and g satisfying (23) is denoted by \mathcal{B} .
 The set of all f and g satisfying (24) is denoted by \mathcal{C} .
 The set of all f and g satisfying (25) is denoted by \mathcal{D} .

Analysis of Variance Calculations

GROUP I ANALYSIS: This group comprises all the slope values for torques of 3, 10 and 20 inch pounds, using eight operators and five handwheels.

Table 5a.

Operator	Handwheel	4"	5"	7"	10"	14"
TERBO:	T=3 in.lbs.	.419	.458	.671	.435	.505
	T=10 " "	.647	.536	.607	.499	.383
	T=20 " "	.781	.895	.812	.624	.611
- - - - -						
COSTER:	T=3 in.lbs.	.288	.418	.337	.259	.318
	T=10 " "	.464	.530	.667	.495	.491
	T=20 " "	1.099	.620	.787	.640	.509
- - - - -						
NESTORY:	T=3 in.lbs.	.354	.330	.337	.392	.336
	T=10 " "	.300	.452	.432	.354	.396
	T=20 " "	.803	1.011	.831	.688	.448
- - - - -						
PICHMAN:	T=3 in.lbs.	.405	.591	.400	.495	.453
	T=10 " "	.803	.499	.806	.819	.575
	T=20 " "	.977	.940	.553	.429	.655
- - - - -						
CROSSK:	T=3 in.lbs.	.467	.462	.451	.390	.362
	T=10 " "	.673	.606	.435	.543	.440
	T=20 " "	.770	.848	.606	.587	.507
- - - - -						
LINDQUIST	T=3 in.lbs.	.359	.432	.422	.346	.407
	T=10 " "	.744	.513	.634	.527	.477
	T=20 " "	.816	.836	.596	.548	.606
- - - - -						
ADELBERG:	T=3 in.lbs.	.479	.449	.443	.643	.616
	T=10 " "	.818	.657	.496	.475	.620
	T=20 " "	.990	.804	.849	.731	.591
- - - - -						
REFSUM:	T=3 in.lbs.	.606	.549	.485	.575	.535
	T=10 " "	.743	.692	.622	.697	.581
	T=20 " "	2.186	.998	.647	.761	.752

TOTALS = 17.176 14.926 13.226 12.952 12.064

GT(X) = 70.344 = T GT(X²) = 47.511824 = $\sum_{w,t,u} x_{wtu}^2$

RECORD OF THE BOARD OF DIRECTORS

At a meeting of the Board of Directors held at the City of New York, New York, on the 1st day of January, 1901.

The following resolutions were adopted, to-wit:

Resolved, That the Board of Directors do hereby

RESOLUTIONS

RESOLUTION	1	2	3	4	5	6
1. That the Board of Directors do hereby	100	100	100	100	100	100
2. That the Board of Directors do hereby	100	100	100	100	100	100
3. That the Board of Directors do hereby	100	100	100	100	100	100
4. That the Board of Directors do hereby	100	100	100	100	100	100
5. That the Board of Directors do hereby	100	100	100	100	100	100
6. That the Board of Directors do hereby	100	100	100	100	100	100
7. That the Board of Directors do hereby	100	100	100	100	100	100
8. That the Board of Directors do hereby	100	100	100	100	100	100
9. That the Board of Directors do hereby	100	100	100	100	100	100
10. That the Board of Directors do hereby	100	100	100	100	100	100
11. That the Board of Directors do hereby	100	100	100	100	100	100
12. That the Board of Directors do hereby	100	100	100	100	100	100
13. That the Board of Directors do hereby	100	100	100	100	100	100
14. That the Board of Directors do hereby	100	100	100	100	100	100
15. That the Board of Directors do hereby	100	100	100	100	100	100
16. That the Board of Directors do hereby	100	100	100	100	100	100
17. That the Board of Directors do hereby	100	100	100	100	100	100
18. That the Board of Directors do hereby	100	100	100	100	100	100
19. That the Board of Directors do hereby	100	100	100	100	100	100
20. That the Board of Directors do hereby	100	100	100	100	100	100

WITNESSED the hand of the President and the Secretary of the Board of Directors, this 1st day of January, 1901.

President: [Signature] Secretary: [Signature]

Table 5b.

HANDWHEELS

<u>Operators</u>	<u>4"</u>	<u>5"</u>	<u>7"</u>	<u>10"</u>	<u>14"</u>	<u>T_o</u>
TERBO	1.847	1.889	1.890	1.558	1.449	8.683
COSTER	1.751	1.568	1.791	1.374	1.228	7.812
NESTORY	1.637	1.793	1.300	1.434	1.180	7.344
FICHMAN	2.185	1.830	1.559	1.743	1.683	8.980
CROSSE	1.910	1.916	1.492	1.520	1.309	8.147
LINDQUIST	1.919	1.781	1.652	1.421	1.490	8.263
ADELBERG	2.287	1.910	1.788	1.849	1.827	9.661
REFSUM	<u>3.540</u>	<u>2.239</u>	<u>1.754</u>	<u>2.053</u>	<u>1.868</u>	<u>11.454</u>
T _w =	17.176	14.926	13.226	12.952	12.064	70.344= T

NOTE: Each cell in Table 5b is T_{wo}. Value for each is arrived at by summing three torque values for each wheel-operator combination in Table 5a.

EXAMPLE: 1.847 = .419 / .617 / .781

Table 5c.

TORQUES

	<u>3 in.lbs.</u>	<u>10 in.lbs.</u>	<u>20 in.lbs.</u>	<u>T_o</u>
TERBO	2.288	2.672	3.723	8.683
COSTER	1.600	2.557	3.653	7.812
NESTORY	1.729	2.134	3.481	7.344
FICHMAN	2.144	3.302	3.534	8.980
CROSSE	2.132	2.697	3.318	8.147
LINDQUIST	1.966	2.893	3.402	8.263
ADELBERG	2.630	3.066	3.963	9.661
REFSUM	<u>2.750</u>	<u>3.340</u>	<u>5.364</u>	<u>11.454</u>
T _t =	17.239	22.663	30.442	70.344= T

NOTE: Each cell in Table 5c is T_{to}. Value for each is arrived at by summing five wheel values for each torque-operator combination in Table 5a.

EXAMPLE: 2.288 = .419 / .458 / .471 / .435 / .503

[illegible]

Hand sold in 1910 to J. H. ...
divided at by ...
Hand-sold in 1910 to J. H. ...

$$\text{INT}_t + \text{VOC}_t + \text{QDA}_t = \text{VAB}_t \quad \text{EQUATION 1}$$

5672

$\frac{Y}{\sigma^2}$	$\frac{d \ln L(\theta)}{d \theta}$	$\frac{d^2 \ln L(\theta)}{d \theta^2}$	$\frac{d^3 \ln L(\theta)}{d \theta^3}$	
550.3	557.2	578.3	598.2	550.3
557.7	568.2	590.2	609.1	557.7
567.7	578.2	602.2	620.1	567.7
580.3	588.2	613.2	631.1	580.3
591.3	598.2	624.2	642.1	591.3
601.3	608.2	635.2	653.1	601.3
611.3	618.2	646.2	664.1	611.3
621.3	628.2	657.2	675.1	621.3
631.3	638.2	668.2	686.1	631.3
641.3	648.2	679.2	697.1	641.3
651.3	658.2	690.2	708.1	651.3
661.3	668.2	701.2	719.1	661.3
671.3	678.2	712.2	730.1	671.3
681.3	688.2	723.2	741.1	681.3
691.3	698.2	734.2	752.1	691.3
701.3	708.2	745.2	763.1	701.3
711.3	718.2	756.2	774.1	711.3
721.3	728.2	767.2	785.1	721.3
731.3	738.2	778.2	796.1	731.3
741.3	748.2	789.2	807.1	741.3
751.3	758.2	800.2	818.1	751.3
761.3	768.2	811.2	829.1	761.3
771.3	778.2	822.2	840.1	771.3
781.3	788.2	833.2	851.1	781.3
791.3	798.2	844.2	862.1	791.3
801.3	808.2	855.2	873.1	801.3
811.3	818.2	866.2	884.1	811.3
821.3	828.2	877.2	895.1	821.3
831.3	838.2	888.2	906.1	831.3
841.3	848.2	899.2	917.1	841.3
851.3	858.2	910.2	928.1	851.3
861.3	868.2	921.2	939.1	861.3
871.3	878.2	932.2	950.1	871.3
881.3	888.2	943.2	961.1	881.3
891.3	898.2	954.2	972.1	891.3
901.3	908.2	965.2	983.1	901.3
911.3	918.2	976.2	994.1	911.3
921.3	928.2	987.2	1005.1	921.3
931.3	938.2	998.2	1016.1	931.3
941.3	948.2	1009.2	1027.1	941.3
951.3	958.2	1020.2	1038.1	951.3
961.3	968.2	1031.2	1049.1	961.3
971.3	978.2	1042.2	1060.1	971.3
981.3	988.2	1053.2	1071.1	981.3
991.3	998.2	1064.2	1082.1	991.3
1001.3	1008.2	1075.2	1093.1	1001.3
1011.3	1018.2	1086.2	1104.1	1011.3
1021.3	1028.2	1097.2	1115.1	1021.3
1031.3	1038.2	1108.2	1126.1	1031.3
1041.3	1048.2	1119.2	1137.1	1041.3
1051.3	1058.2	1130.2	1148.1	1051.3
1061.3	1068.2	1141.2	1159.1	1061.3
1071.3	1078.2	1152.2	1170.1	1071.3
1081.3	1088.2	1163.2	1181.1	1081.3
1091.3	1098.2	1174.2	1192.1	1091.3
1101.3	1108.2	1185.2	1203.1	1101.3
1111.3	1118.2	1196.2	1214.1	1111.3
1121.3	1128.2	1207.2	1225.1	1121.3
1131.3	1138.2	1218.2	1236.1	1131.3
1141.3	1148.2	1229.2	1247.1	1141.3
1151.3	1158.2	1240.2	1258.1	1151.3
1161.3	1168.2	1251.2	1269.1	1161.3
1171.3	1178.2	1262.2	1280.1	1171.3
1181.3	1188.2	1273.2	1291.1	1181.3
1191.3	1198.2	1284.2	1302.1	1191.3
1201.3	1208.2	1295.2	1313.1	1201.3
1211.3	1218.2	1306.2	1324.1	1211.3
1221.3	1228.2	1317.2	1335.1	1221.3
1231.3	1238.2	1328.2	1346.1	1231.3
1241.3	1248.2	1339.2	1357.1	1241.3
1251.3	1258.2	1350.2	1368.1	1251.3
1261.3	1268.2	1361.2	1379.1	1261.3
1271.3	1278.2	1372.2	1390.1	1271.3
1281.3	1288.2	1383.2	1401.1	1281.3
1291.3	1298.2	1394.2	1412.1	1291.3
1301.3	1308.2	1405.2	1423.1	1301.3
1311.3	1318.2	1416.2	1434.1	1311.3
1321.3	1328.2	1427.2	1445.1	1321.3
1331.3	1338.2	1438.2	1456.1	1331.3
1341.3	1348.2	1449.2	1467.1	1341.3
1351.3	1358.2	1460.2	1478.1	1351.3
1361.3	1368.2	1471.2	1489.1	1361.3
1371.3	1378.2	1482.2	1500.1	1371.3
1381.3	1388.2	1493.2	1511.1	1381.3
1391.3	1398.2	1504.2	1522.1	1391.3
1401.3	1408.2	1515.2	1533.1	1401.3
1411.3	1418.2	1526.2	1544.1	1411.3
1421.3	1428.2	1537.2	1555.1	1421.3
1431.3	1438.2	1548.2	1566.1	1431.3
1441.3	1448.2	1559.2	1577.1	1441.3
1451.3	1458.2	1570.2	1588.1	1451.3
1461.3	1468.2	1581.2	1599.1	1461.3
1471.3	1478.2	1592.2	1610.1	1471.3
1481.3	1488.2	1603.2	1621.1	1481.3
1491.3	1498.2	1614.2	1632.1	1491.3
1501.3	1508.2	1625.2	1643.1	1501.3
1511.3	1518.2	1636.2	1654.1	1511.3
1521.3	1528.2	1647.2	1665.1	1521.3
1531.3	1538.2	1658.2	1676.1	1531.3
1541.3	1548.2	1669.2	1687.1	1541.3
1551.3	1558.2	1680.2	1698.1	1551.3
1561.3	1568.2	1691.2	1709.1	1561.3
1571.3	1578.2	1702.2	1720.1	1571.3
1581.3	1588.2	1713.2	1731.1	1581.3
1591.3	1598.2	1724.2	1742.1	1591.3
1601.3	1608.2	1735.2	1753.1	1601.3
1611.3	1618.2	1746.2	1764.1	1611.3
1621.3	1628.2	1757.2	1775.1	1621.3
1631.3	1638.2	1768.2	1786.1	1631.3
1641.3	1648.2	1779.2	1797.1	1641.3
1651.3	1658.2	1790.2	1808.1	1651.3
1661.3	1668.2	1801.2	1819.1	1661.3
1671.3	1678.2	1812.2	1830.1	1671.3
1681.3	1688.2	1823.2	1841.1	1681.3
1691.3	1698.2	1834.2	1852.1	1691.3
1701.3	1708.2	1845.2	1863.1	1701.3
1711.3	1718.2	1856.2	1874.1	1711.3
1721.3	1728.2	1867.2	1885.1	1721.3
1731.3	1738.2	1878.2	1896.1	1731.3
1741.3	1748.2	1889.2	1907.1	1741.3
1751.3	1758.2	1900.2	1918.1	1751.3
1761.3	1768.2	1911.2	1929.1	1761.3
1771.3	1778.2	1922.2	1940.1	1771.3
1781.3	1788.2	1933.2	1951.1	1781.3
1791.3	1798.2	1944.2	1962.1	1791.3
1801.3	1808.2	1955.2	1973.1	1801.3
1811.3	1818.2	1966.2	1984.1	1811.3
1821.3	1828.2	1977.2	1995.1	1821.3
1831.3	1838.2	1988.2	2006.1	1831.3
1841.3	1848.2	1999.2	2017.1	1841.3
1851.3	1858.2	2010.2	2028.1	1851.3
1861.3	1868.2	2021.2	2039.1	1861.3
1871.3	1878.2	2032.2	2050.1	1871.3
1881.3	1888.2	2043.2	2061.1	1881.3
1891.3	1898.2	2054.2	2072.1	1891.3
1901.3	1908.2	2065.2	2083.1	1901.3
1911.3	1918.2	2076.2	2094.1	1911.3
1921.3	1928.2	2087.2	2105.1	1921.3
1931.3	1938.2	2098.2	2116.1	1931.3
1941.3	1948.2	2109.2	2127.1	1941.3
1951.3	1958.2	2120.2	2138.1	1951.3
1961.3	1968.2	2131.2	2149.1	1961.3
1971.3	1978.2	2142.2	2160.1	1971.3
1981.3	1988.2	2153.2	2171.1	1981.3
1991.3	1998.2	2164.2	2182.1	1991.3
2001.3	2008.2	2175.2	2193.1	2001.3
2011.3	2018.2	2186.2	2204.1	2011.3
2021.3	2028.2	2197.2	2215.1	2021.3
2031.3	2038.2	2208.2	2226.1	2031.3
2041.3	2048.2	2219.2	2237.1	2041.3
2051.3	2058.2	2230.2	2248.1	2051.3
2061.3	2068.2	2241.2	2259.1	2061.3
2071.3	2078.2	2252.2	2270.1	2071.3
2081.3	2088.2	2263.2	2281.1	2081.3
2091.3	2098.2	2274.2	2292.1	2091.3
2101.3	2108.2	2285.2	2303.1	2101.3
2111.3	2118.2	2296.2	2314.1	2111.3
2121.3	2128.2	2307.2	2325.1	2121.3
2131.3	2138.2	2318.2	2336.1	2131.3
2141.3	2148.2	2329.2	2347.1	2141.3
2151.3	2158.2	2340.2	2358.1	2151.3
2161.3	2168.2	2351.2	2369.1	2161.3
2171.3	2178.2	2362.2	2380.1	2171.3
2181.3	2188.2	2373.2	2391.1	2181.3
2191.3	2198.2	2384.2	2402.1	2191.3
2201.3	2208.2	2395.2	2413.1	2201.3
2211.3	2218.2	2406.2	2424.1	2211.3
2221.3	2228.2	2417.2	2435.1	2221.3
2231.3	2238.2	2428.2	2446.1	2231.3
2241.3	2248.2	2439.2	2457.1	2241.3
2251.3	2258.2	2450.2	2468.1	2251.3
2261.3	2268.2	2461.2	2479.1	2261.3
2271.3	2278.2	2472.2	2490.1	2271.3
2281.3	2288.2	2483.2	2501.1	2281.3
2291.3	2298.2	2494.2	2512.1	2291.3
2301.3	2308.2	2505.2	2523.1	2301.3
2311.3	2318.2	2516.2	2534.1	2311.3
2321.3	2328.2	2527.2	2545.1	2321.3
2331.3	2338.2	2538.2	2556.1	2331.3
2341.3	2348.2	2549.2	2567.1	2341.3
2351.3	2358.2	2560.2	2578.1	2351.3
2361.3	2368.2	2571.2	2589.1	2361.3
2371.3	2378.2	2582.2	2600.1	2371.3
2381.3	2388.2	2593.2	2611.1	2381.3
2391.3	2398.2	2604.2	2622.1	2391.3
2401.3	2408.2	2615.2	2633.1	2401.3
2411.3	2418.2	2626.2	2644.1	2411.3
2421.3	2428.2	2637.2	2655.1	2421.3
2431.3	2438.2	2648.2	2666.1	2431.3
2441.3	2448.2	2659.2	2677.1	2441.3
2451.3	2458.2	2670.2	2688.1	2451.3
2461.3	2468.2	2681.2	2699.1	2461.3
2471.3	2478.2	2692.2	2710.1	2471.3
2481.3	2488.2	2703.2	2721.1	2481.3
2491.3	2498.2	2714.2	2732.1	2491.3
2501.3	2508.2	2725.2	2743.1	2501.3
2511.3	2518.2	2736.2	2754.1	2511.3
2521.3	2528.2	2747.2	2765.1	2521.3
2531.3	2538.2	2758.2	2776.1	2531.3
2541.3	2548.2	2769.2	2787.1	2541.3
2551.3	2558.2	2780.2	2798.1	2551.3
2561.3	2568.2	2791.2	2809.1	2561.3
2571.3	2578.2	2802.2	2820.1	2571.3
2581.3	2588.2	2813.2	2831.1	2581.3
2591.3	2598.2	2824.2	2842.1	2591.3
2601.3	2608.2	2835.2	2853.1	2601.3
2611.3	2618.2	2846.2	2864.1	2611.3
2621.3	2628.2	2857.2	2875.1	2621.3
2631.3	2638.2	2868.2	2886.1	2631.3
2641.3	2648.2	2879.2	2897.1	2641.3
2651.3	2658.2	2890.2	2908.1	2651.3
2661.3	2668.2	2901.2	2919.1	

NOTE: Some data in Table 2 is from the 1970 Census. The data in Table 3 is from the 1980 Census. The data in Table 4 is from the 1990 Census. The data in Table 5 is from the 2000 Census. The data in Table 6 is from the 2010 Census. The data in Table 7 is from the 2020 Census.

$$200.4 \times 10^3 \text{ J} + 572.4 \times 10^3 \text{ J} + 273.4 \times 10^3 \text{ J} + 853.4 \times 10^3 \text{ J} + 641.4 \times 10^3 \text{ J} = 2541.0 \times 10^3 \text{ J} \quad (2.70)$$

Table 5d.

TORQUES

<u>Handwheels</u>	<u>5 in.lbs.</u>	<u>10 in.lbs.</u>	<u>20 in.lbs.</u>	<u>T_w</u>
4"	3.357	5.397	8.422	17.176
5"	3.489	4.485	6.952	14.926
7"	3.346	4.499	5.381	13.226
10"	3.515	4.409	5.029	12.952
14"	<u>3.532</u>	<u>3.873</u>	<u>4.659</u>	<u>12.064</u>
T _t :	17.239	22.663	30.442	70.344 = T

Table 5e.

<u>Item Source</u> <u>of Variation</u>		<u>F TESTS</u>						
		<u>df.</u>	<u>SS</u>	<u>Mean</u> <u>Square</u>	<u>Source</u>	<u>F_{ob}</u>	<u>F_{.05}</u>	<u>F_{.01}</u>
A	Wheels 1-5	4	.681927	.170482	A/E	9.10	2.71	4.07
B	Torques 1-3	2	2.202099	1.101049	B/F	53.14	3.74	6.51
C	Operators 1-3	7	.776106	.110872	C/G E/F	3.45	2.08	2.82
D	Wheels x Torques	8	.391720	.048973	D/G	1.96	2.11	2.64
E	Wheels x Operators	28	.524594	.018973	E/G	.76	1.77	2.29
F	Torques x Operators	14	.290063	.020719	F/G	.84	2.23	2.19
G	Error (WxTx0)	56	1.409402	.025163				
H	Total	119	6.275971	.052739				

$$\begin{aligned}
 \text{(H) Total SS} &= \sum_{w,t,o} \frac{T^2}{n} - \frac{T^2}{120} \\
 &= 47.511624 - \frac{70344}{120} \\
 &= 6.275971
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{wo} &= \sum_{w,o} \frac{T^2}{3} - \frac{T^2}{120} \\
 &= \frac{129.654840}{3} - 41.235653 \\
 &= 1.982627
 \end{aligned}$$

$$\begin{aligned}
 \text{(A) Wheels SS} &= \sum_w \frac{T^2}{24} - \frac{T^2}{120} \\
 &= \frac{1006.021928}{24} - 41.235653 \\
 &= .681927
 \end{aligned}$$

$$\begin{aligned}
 \text{(C) Operator SS} &= \sum_o \frac{T^2}{15} - \frac{T^2}{120} \\
 &= \frac{630.176384}{15} - 41.235653 \\
 &= .776106
 \end{aligned}$$

$$\begin{aligned}
 \text{(E) Wheels x Operators SS} &= \text{Sub Total SS}_{wo} - \text{Wheels SS} - \text{Operators SS} \\
 &= 1.982627 - .681927 - .776106 \\
 &= .524594
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{to} &= \sum_{t,o} \frac{T^2}{5} - \frac{T^2}{120} \\
 &= \frac{222.519604}{5} - 41.235653 \\
 &= 3.268268
 \end{aligned}$$

$$\begin{aligned}
 \text{(B) Torque SS} &= \sum_t \frac{T^2}{40} - \frac{T^2}{120} \\
 &= \frac{1737.510054}{40} - 41.235653 \\
 &= 2.202099
 \end{aligned}$$

$$\begin{aligned}
 \text{(F) Torque x Operators SS}_{to} &= \text{Sub Total SS}_{to} - \text{Torque SS} - \text{Operator SS} \\
 &= 3.268268 - 2.202099 - .776106 \\
 &= .290063
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{tw} &= \sum_{t,w} \frac{T^2}{8} - \frac{T^2}{120} \\
 &= \frac{356.091674}{8} - 41.235653 \\
 &= 3.275806
 \end{aligned}$$

$$\frac{2.0007}{0.01} = 200.07$$

$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

$$\frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} = \frac{1}{n} \sum_{i=1}^n \frac{1}{x_i} \quad (A)$$

$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$$

[illegible]

$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
 $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$
 $\frac{1}{16} \times \frac{1}{16} = \frac{1}{256}$
 $\frac{1}{256} \times \frac{1}{256} = \frac{1}{65536}$
 $\frac{1}{65536} \times \frac{1}{65536} = \frac{1}{4294967296}$

[illegible]

[illegible]

$$\begin{aligned}
 (D) \quad \text{Torque x Wheel SS} &= \text{Sub Total SS}_{tw} - \text{Torque SS} \\
 &\quad - \text{Wheel SS} \\
 &= 3.275806 - 2.202099 - .681927 \\
 &= .391780
 \end{aligned}$$

$$\begin{aligned}
 (E) \quad \text{Error SS} &= \text{Total SS} - (WSS + TSS + OSS + W \times TSS) \\
 &\quad (+ W \times OSS + T \times OSS) \\
 &= 6.275971 - (.681927 + 2.202099 + .776106) \\
 &\quad (+ .391780 + .524594 + .290063) \\
 &= 1.409402
 \end{aligned}$$

10. The number of ways in which 1000 can be expressed as the sum of 10 squares is 10.

[illegible]

GROUP II ANALYSIS: This group comprises slope values for seven torques, eight operators and three handwheels.

Table 6a.

OPERATORS*

	TOR.	1	2	3	4	5	6	7	8
W 7"	3	.471	.337	.337	.400	.451	.422	.443	.485
H	10	.607	.667	.432	.608	.435	.634	.496	.622
E	20	.812	.787	.536	.553	.606	.596	.849	.647
E	30	1.012	1.144	.692	.535	.938	.943	1.037	.910
L	40	.836	1.564	.753	.748	1.007	1.050	.924	1.128
S	50	.989	1.545	.890	.920	1.304	1.065	1.038	1.494
	60	2.101	1.389	1.145	1.211	1.413	1.093	.992	1.381

TOTALS $\bar{X} = 48.422$ $\bar{X}^2 = 49.382920$

10"	3	.435	.239	.392	.395	.390	.346	.643	.575
	10	.499	.495	.354	.819	.543	.527	.475	.697
	20	.624	.640	.688	.429	.537	.548	.731	.781
	30	1.040	.790	.569	.623	.557	.632	.752	.876
	40	.753	1.088	.778	.768	.883	.829	.855	.904
	50	.754	1.017	.712	.874	.730	1.043	.850	1.035
	60	.971	1.046	.858	.914	.668	.808	.824	1.124

TOTALS $\bar{X} = 39.877$ $\bar{X}^2 = 30.839827$

14"	3	.505	.318	.336	.453	.362	.407	.616	.535
	10	.363	.401	.396	.575	.440	.477	.620	.581
	20	.611	.509	.448	.635	.507	.608	.591	.752
	30	.671	.848	.487	.728	.658	.728	.704	.873
	40	.750	.817	.698	.611	.653	.825	.643	.991
	50	.797	.807	.632	.728	.736	.748	.832	.834
	60	.800	.877	.689	.730	.897	.805	1.007	1.095

TOTALS $\bar{X} = 36.580$ $\bar{X}^2 = 25.579906$

$$GT(\bar{X}) = 124.889 = T; GT(\bar{X}^2) = 105.802653 = \sum_{w,t,o} \bar{X}^2$$

* Because of space limitations it was necessary to assign numbers to the operators. The operators are numbered at the top of Table 6a in the same sequence as they were presented in the previous tables.

GROUP II (continued) This group comprises those cases for
which the following data are available:

Table 6a.

Continued

1	2	3	4	5	6	7	8	9	10
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100

100 100 100 100 100 100 100 100 100 100

1	2	3	4	5	6	7	8	9	10
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100

100 100 100 100 100 100 100 100 100 100

1	2	3	4	5	6	7	8	9	10
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100

100 100 100 100 100 100 100 100 100 100

100 100 100 100 100 100 100 100 100 100

* Groups of cases identified as not necessary for analysis
are shown in the Appendix. The Appendix is included
as an aid to the reader in the case of groups of cases
which are not shown in the Appendix.

Table 6b.

WHEELS

<u>OPERATORS</u>	<u>7"</u>	<u>10"</u>	<u>14"</u>	<u>T₀</u>
1	6.628	5.076	4.517	16.421
2	7.453	5.315	4.577	17.325
3	4.765	4.351	3.686	12.822
4	4.973	4.922	4.460	14.355
5	6.154	4.358	4.233	14.745
6	5.803	4.733	4.594	15.130
7	5.779	5.130	4.813	15.722
8	<u>6.667</u>	<u>5.992</u>	<u>5.710</u>	<u>18.369</u>
$T_w = 48.422 \quad 39.877 \quad 36.590 \quad 124.889 = T$				

NOTE: Each cell in Table 6b is T_{wo} . Value for each cell is arrived at by summing seven wheel values for each torque-operator combination in Table 6a.

EXAMPLE: $6.628 = .471 + .337 + .337 + .400 + .451$
 $+ .422 + .443 + .485$

Table 6c.

TORQUES

	<u>3 in.</u>	<u>10 in.</u>	<u>20 in.</u>	<u>30 in.</u>	<u>40 in.</u>	<u>50 in.</u>	<u>60 in.</u>	<u>T₀</u>
	<u>lbs.</u>	<u>lbs.</u>	<u>lbs.</u>	<u>lbs.</u>	<u>lbs.</u>	<u>lbs.</u>	<u>lbs.</u>	
O 1	1.411	1.439	2.047	2.723	2.339	2.540	3.872	16.421
F 2	.894	1.563	1.936	2.782	3.439	3.369	3.312	17.325
E 3	1.065	1.182	1.672	1.748	2.229	2.234	2.692	12.822
R 4	1.348	2.000	1.617	1.866	2.127	2.522	2.855	14.355
A 5	1.203	1.418	1.700	2.153	2.523	2.770	2.978	14.745
T 6	1.175	1.638	1.750	2.301	2.704	2.656	2.706	15.130
O 7	1.702	1.591	2.171	2.493	2.422	2.720	2.623	15.722
R 8	<u>1.545</u>	<u>1.900</u>	<u>2.180</u>	<u>2.659</u>	<u>3.023</u>	<u>3.413</u>	<u>3.599</u>	<u>18.369</u>
T_t :	<u>10.393</u>	<u>12.781</u>	<u>15.073</u>	<u>18.745</u>	<u>20.836</u>	<u>22.424</u>	<u>24.637</u>	<u>124.889</u>

NOTE: Each cell in Table 6c is T_{to} . Value for each cell is arrived at by summing three wheel values for each torque-wheel combination in Table 6a.

EXAMPLE: $1.411 = .471 + .435 + .505$

TABLE NO. 1
Summary of the results of the tests conducted on the various types of concrete beams.

Beam No.	Length, ft.	Width, in.	Height, in.	Weight, lb.	Modulus of Elasticity, lb./sq. in.
1	10.0	12.0	12.0	1,200	3,000,000
2	10.0	12.0	12.0	1,200	3,000,000
3	10.0	12.0	12.0	1,200	3,000,000
4	10.0	12.0	12.0	1,200	3,000,000
5	10.0	12.0	12.0	1,200	3,000,000
6	10.0	12.0	12.0	1,200	3,000,000
7	10.0	12.0	12.0	1,200	3,000,000
8	10.0	12.0	12.0	1,200	3,000,000
9	10.0	12.0	12.0	1,200	3,000,000
10	10.0	12.0	12.0	1,200	3,000,000
11	10.0	12.0	12.0	1,200	3,000,000
12	10.0	12.0	12.0	1,200	3,000,000
13	10.0	12.0	12.0	1,200	3,000,000
14	10.0	12.0	12.0	1,200	3,000,000
15	10.0	12.0	12.0	1,200	3,000,000
16	10.0	12.0	12.0	1,200	3,000,000
17	10.0	12.0	12.0	1,200	3,000,000
18	10.0	12.0	12.0	1,200	3,000,000
19	10.0	12.0	12.0	1,200	3,000,000
20	10.0	12.0	12.0	1,200	3,000,000

The above table gives a summary of the results of the tests conducted on the various types of concrete beams. The modulus of elasticity was determined by the method of the American Society of Civil Engineers, and the weight was determined by weighing the beams on a platform scale.

It will be seen from the above table that the modulus of elasticity of the concrete beams varies from 3,000,000 to 3,500,000 lb./sq. in., and the weight varies from 1,200 to 1,500 lb.

TABLE NO. 2
Summary of the results of the tests conducted on the various types of concrete beams.

Beam No.	Length, ft.	Width, in.	Height, in.	Weight, lb.	Modulus of Elasticity, lb./sq. in.
1	10.0	12.0	12.0	1,200	3,000,000
2	10.0	12.0	12.0	1,200	3,000,000
3	10.0	12.0	12.0	1,200	3,000,000
4	10.0	12.0	12.0	1,200	3,000,000
5	10.0	12.0	12.0	1,200	3,000,000
6	10.0	12.0	12.0	1,200	3,000,000
7	10.0	12.0	12.0	1,200	3,000,000
8	10.0	12.0	12.0	1,200	3,000,000
9	10.0	12.0	12.0	1,200	3,000,000
10	10.0	12.0	12.0	1,200	3,000,000
11	10.0	12.0	12.0	1,200	3,000,000
12	10.0	12.0	12.0	1,200	3,000,000
13	10.0	12.0	12.0	1,200	3,000,000
14	10.0	12.0	12.0	1,200	3,000,000
15	10.0	12.0	12.0	1,200	3,000,000
16	10.0	12.0	12.0	1,200	3,000,000
17	10.0	12.0	12.0	1,200	3,000,000
18	10.0	12.0	12.0	1,200	3,000,000
19	10.0	12.0	12.0	1,200	3,000,000
20	10.0	12.0	12.0	1,200	3,000,000

The above table gives a summary of the results of the tests conducted on the various types of concrete beams. The modulus of elasticity was determined by the method of the American Society of Civil Engineers, and the weight was determined by weighing the beams on a platform scale.

It will be seen from the above table that the modulus of elasticity of the concrete beams varies from 3,000,000 to 3,500,000 lb./sq. in., and the weight varies from 1,200 to 1,500 lb.

Table 6d.

TORQUES

W	3 in.	10 in.	20 in.	30 in.	40 in.	50 in.	60 in.	
H	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	T_w
E								
E 7"	3.346	4.499	5.386	7.211	8.010	9.245	10.725	43.422
L 10"	3.515	4.409	5.028	5.839	6.858	7.015	7.213	39.877
S 14"	3.532	3.873	4.659	5.695	5.963	6.164	6.699	36.590
T_t	10.393	12.781	15.073	18.745	20.936	22.424	24.637	124.889

NOTE: Each cell in Table 6d is T_{tw} . Value for each cell is arrived at by summing eight operator values for each torque-wheel combination in Table 6a.

EXAMPLE: $3.346 = .471 + .337 + .337 + .400 + .451$
 $+ .422 + .443 + .435$

Table 6e.

				F TESTS			
Item Source of Variation	df.	SS	Mean Square	Source	F_{ob}	$F_{.05}$	$F_{.01}$
A Wheels 3-5	2	1.332248	.666124	A/E	22.48	3.74	6.51
B Torques 1-7	6	6.904737	1.150793	B/F	69.48	2.32	3.26
C Operators 1-3	7	1.026198	.146600	$\frac{C/G}{E/F}$	5.36	2.31	3.31
D Wheels x Torques	12	1.002350	.083530	D/G	4.37	2.36	3.48
E Wheels x Operators	14	.414935	.029638	E/G	1.56	2.20	3.13
F Torques x Operators	42	.695670	.016564	F/G	.38	1.59	1.93
G Error (WxTxO)	84	1.585608	.018976				
H Total	167	12.961206	.076156				

	01	02	03	04	05	06	07	08	09	10	11	12
01	01	02	03	04	05	06	07	08	09	10	11	12
02	01	02	03	04	05	06	07	08	09	10	11	12
03	01	02	03	04	05	06	07	08	09	10	11	12
04	01	02	03	04	05	06	07	08	09	10	11	12
05	01	02	03	04	05	06	07	08	09	10	11	12
06	01	02	03	04	05	06	07	08	09	10	11	12
07	01	02	03	04	05	06	07	08	09	10	11	12
08	01	02	03	04	05	06	07	08	09	10	11	12
09	01	02	03	04	05	06	07	08	09	10	11	12
10	01	02	03	04	05	06	07	08	09	10	11	12
11	01	02	03	04	05	06	07	08	09	10	11	12
12	01	02	03	04	05	06	07	08	09	10	11	12

THE
WELL IS 100 FEET DEEP AND IS 10 FEET IN DIAMETER.
WELL IS 100 FEET DEEP AND IS 10 FEET IN DIAMETER.
WELL IS 100 FEET DEEP AND IS 10 FEET IN DIAMETER.

109. 4 008, 4 762, 4 768, 4 179, x 145,6 1419888
 804, 4 534, 4 804, 4

[illegible]

$$\begin{aligned}
 (H) \quad \text{Total SS} &= \sum_{w,t,o} T_{wto}^2 - \frac{T^2}{168} \\
 &= 105.802653 - 92.840847 \\
 &= 12.961806
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{wo} &= \sum_{w,o} \frac{T_{wo}^2}{7} - \frac{T^2}{168} \\
 &= 95.614228 - 92.840847 \\
 &= 2.773381
 \end{aligned}$$

$$\begin{aligned}
 (A) \quad \text{Wheels SS} &= \sum_{w,w} \frac{T_w^2}{56} - \frac{T^2}{168} \\
 &= 95.173095 - 92.840847 \\
 &= 1.332248
 \end{aligned}$$

$$\begin{aligned}
 (C) \quad \text{Operator SS} &= \sum_o \frac{T_o^2}{61} - \frac{T^2}{168} \\
 &= 93.887045 - 92.840847 \\
 &= 1.026198
 \end{aligned}$$

$$\begin{aligned}
 (E) \quad \text{Wheels x} \\
 \text{Operators SS} &= \text{Sub Total SS}_{wo} - \text{Wheels SS} - \text{Operators SS} \\
 &= 2.773381 - 1.332248 - 1.026198 \\
 &= .414935
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{to} &= \sum_{t,o} \frac{T_{to}^2}{8} - \frac{T^2}{168} \\
 &= 101.467502 - 92.840847 \\
 &= 8.626655
 \end{aligned}$$

$$\begin{aligned}
 (B) \quad \text{Torque SS} &= \sum_t T_t^2 - \frac{T^2}{168} \\
 &= 99.745634 - 92.840847 \\
 &= 6.904787
 \end{aligned}$$

$$\begin{aligned}
 (F) \quad \text{Torque} \\
 \text{x Operators SS} &= \text{Sub Total SS}_{to} - \text{Torque SS} - \text{Operator SS} \\
 &= 8.626655 - 6.904787 - 1.026198 \\
 &= .695670
 \end{aligned}$$

$$\begin{aligned}
 \text{Sub Total SS}_{tw} &= \sum_{t,w} \frac{T_{tw}^2}{8} - \frac{T^2}{168} \\
 &= 102.080242 - 92.840847 \\
 &= 9.239395
 \end{aligned}$$

(1) Total = 100

100 - 100 = 0

100 - 100 = 0

[illegible]

$$\begin{aligned}
 \text{(D) Torque x} \\
 \text{Wheel SS} &= \text{Sub Total SS}_{\text{CW}} - \text{Torque SS} - \text{Wheel SS} \\
 &= 9.239395 - 6.904787 - 1.332243 \\
 &= 1.002360
 \end{aligned}$$

$$\begin{aligned}
 \text{(E) Error SS} &= \text{Total SS} - (A + B + C + D + E + F) \\
 &= 12.961806 - 11.376198 \\
 &= 1.585608
 \end{aligned}$$

Calculation of Confidence Limits of the Means

$$\begin{aligned}
 \text{Conf. Limit} \\
 \text{of Mean} &= t_{.05} \times S = \frac{2.35 \times .0993}{\sqrt{8}} = \pm .083 \\
 \text{(Task = 4-5)} &
 \end{aligned}$$

Where $t_{.05}$ = Student's t at the 95% confidence level for $N-1 = 7$ degrees of freedom.

$$S = \text{Standard Error} = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N-1}}$$

$N = 8$ = Number of operators

X = Value of slope for each operator.

(21) $\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n f\left(\frac{k}{n}\right) = \int_0^1 f(x) dx$

$$\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n f\left(\frac{k}{n}\right) = \int_0^1 f(x) dx$$

(22) $\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n f\left(\frac{k}{n}\right) = \int_0^1 f(x) dx$

$$\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n f\left(\frac{k}{n}\right) = \int_0^1 f(x) dx$$

Calculation of Gaussian integrals of the form

$$\int_{-\infty}^{\infty} e^{-ax^2} dx = \sqrt{\frac{\pi}{a}}$$

Proof: Let $I = \int_{-\infty}^{\infty} e^{-ax^2} dx$. Then $I^2 = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-a(x^2+y^2)} dx dy$.

$$I^2 = \int_0^{2\pi} \int_0^{\infty} e^{-ar^2} r dr d\theta = \pi \int_0^{\infty} e^{-ar^2} r dr = \frac{\pi}{2a}$$

Therefore $I = \sqrt{\frac{\pi}{a}}$.

Q.E.D.

SLOPE CALCULATION

Chart No. 000Run No. Boat #3 Operator LindquistCHART VALUES

X	Y	X	Y
5	102	94	70
8	103	98	69
12	101	102	69
15	99	106	68
18	97		
21	96		
25	95		
28	93		
32	93		
35	91		
39	90		
42	89		
46	88		
49	87		
53	83		
56	83		
60	82		
64	80		
68	78		
71	80		
75	77		
79	77		
83	75		
87	74		
91	70		

CALCULATED VALUES ΣX 1562 $2 \Sigma XY$ 245104 ΣY 2449 ΣX^2 110674 ΣXY 122552 $N \Sigma XY$ _____ $\Sigma X \Sigma Y$ _____ $(\Sigma X)^2$ _____ $N \Sigma X^2$ _____

$$b = \frac{\Sigma X \Sigma Y - N \Sigma XY}{(\Sigma X)^2 - N \Sigma X^2} = \frac{271336}{769702} = .35251$$

1. The first part of the report is a general statement of the work done during the year.

2. The second part is a detailed account of the work done in each of the several departments.

3. The third part is a summary of the results of the work done during the year.

4. The fourth part is a list of the names of the persons who have been employed during the year.

5. The fifth part is a list of the names of the persons who have been employed during the year.

6. The sixth part is a list of the names of the persons who have been employed during the year.

7. The seventh part is a list of the names of the persons who have been employed during the year.

8. The eighth part is a list of the names of the persons who have been employed during the year.

9. The ninth part is a list of the names of the persons who have been employed during the year.

10. The tenth part is a list of the names of the persons who have been employed during the year.

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THIS EDGE UNDERNEATH

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400

500

600

A

CUBIC CENTIMETERS PER MINUTE

NAME *Handelman*

WT. HI. AGE

NORMAL FROM TABLE

AGE-SEX CORR.

NORMAL STANDARD

C.C. PER MIN.

BMR (TEST 1)

(" 2)

DATE *9 April*

TEMP. (TEST 1) (TEST 2)

BAR. (" 1) (" 2)

DRAW SLOPE LINE FROM LINE "A" TO EDGE "B"

READ AT "A" (TEST 1) (TEST 2)

" "B" (" 1) (" 2)

DIFFERENCE (" 1) (" 2)

TEMP. CORR. (" 1) (" 2)

BAR. (" 1) (" 2)

ACTUAL (" 1) (" 2)

C.C. PER MIN. C.C. PER MIN.

000

Bar #3

600

B

500

400

300

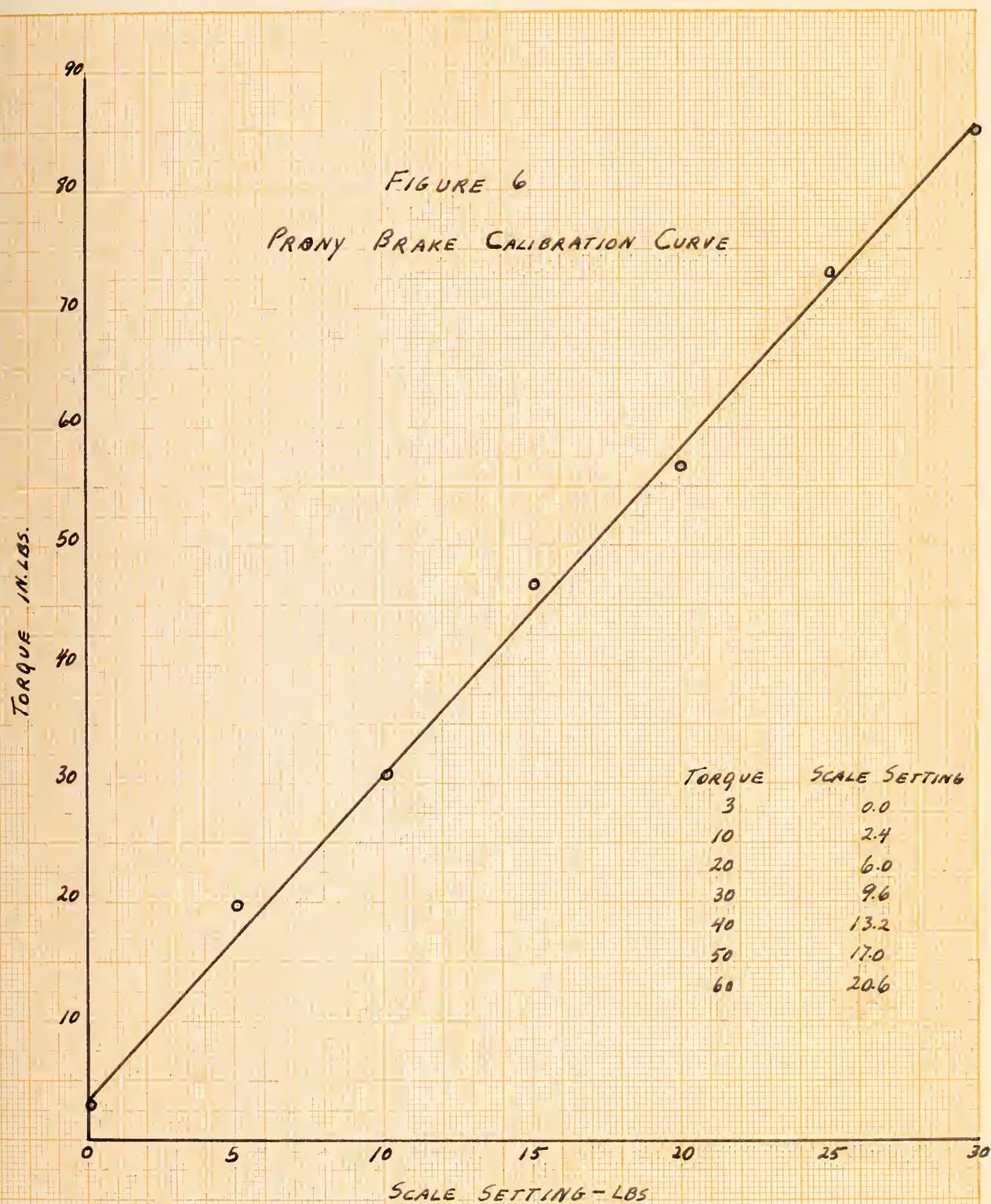
200

100

CUBIC CENTIMETERS PER MINUTE



FORM F
APPROVED FOR USE IN
PURDUE UNIVERSITY



APPENDIX B

SUGGESTIONS FOR FURTHER EXPERIMENTATION

Sources of Error

Although the data of this experiment gave statistically valid results, certain variables did not lend themselves to close control, and each of these variables contributed in some degree to the total accumulated error in each test value. Some of the more important of these error sources are listed below, together with a suggested remedy.

1. Individual differences in the operators took various forms. Variations between the activities of operators for the twenty-four hours preceding the tests, variations in mental attitude (influenced by personal problems), variations in size, strength, age and health and, most important, variations in normal rate and depth of respiration, all had some effect upon the data. A striking example of the variations in rate and depth of respiration is demonstrated by comparison of the data for Hakon Refsum and Joseph Nestory. Refsum's average rate of respiration on the basal tests was seven inhalation-exhalation cycles per minute. Nestory's respiration rate on the same

THEORY OF THE EARTH

Although the fact of this experiment was not
 physically quite possible, various conditions did not lead
 themselves to some extent, and some of these conditions
 described in some degree in the field conditions were
 in fact not true. Some of the most important of these
 other conditions are listed below, together with a suggested
 remedy.

1. Inadequate attention to the conditions
 of the various factors. The various factors
 the analysis of systems for the
 purpose of the various factors and the
 conditions in general (including
 by general conditions), including in this
 arranged, and not being and, and not being
 first, conditions in general and not being
 of conditions, all of which were not
 the same. A similar analysis of the
 conditions in fact and not being of conditions
 is illustrated by conditions of the same
 for the same and the same. The same
 system of conditions in the same way
 was even conditions-conditions-conditions for
 the same. Conditions-conditions-conditions for the same

tests was twenty cycles per minute. The rates were approximately constant from day to day. A closely controlled experiment in which operators of approximately the same respiratory rate and whose activities were supervised for the twenty-four hour period preceding the tests might, to some extent, eliminate this source of error.

2. It was noted that the instant of transfer of the operator from ambient air to pure oxygen had an influence upon the rate at which oxygen was expended from the spirometer bell. When the two-way valve was thrown at the beginning of an inhalation, the operator's lungs, on the first breath, were filled with pure oxygen, and the products of respiration consisted of O_2 , CO_2 and H_2O , the latter two products being absorbed in the metaboline. When the valve was thrown at the beginning of exhalation, the products of respiration consisted of O_2 , N_2 , CO_2 and H_2O . Since the N_2 was not absorbed by the metaboline, it remained in the closed system formed by the operator and the spirometer bell, and subsequently reduced the rate at which the contents of the bell were expended, having a net effect of decreasing the observed

oxygen consumption rate slope. It is strongly recommended that future researchers take this phenomenon into account and avoid this source of error by timing the transfer to pure oxygen so that the transfer occurs at the beginning of an inhalation. This should eliminate the entrance of nitrogen into the system.

3. The capacity of the spirometer bell was insufficient for a complete two-minute run at the higher levels of activity. In several instances, the bell was almost wholly evacuated within one and a half minutes. This enforced the calculation of slope values using the fewer peaks on the wax chart, and it is probable that some error was introduced because of this.
4. Irregularities in respiration, such as excessively long or short breaths, caused high or low peaks on the saw tooth graphs and introduced inaccuracies in the calculation of the true slopes. This was particularly noticeable at the higher levels of performance when the operators were required to exert relatively large forces to keep pace with the metronome. Discussion of this phenomenon with the operators tended to reduce the effect to some degree. However, it is felt that this will always be a source of error in experiments of this nature.

Experimental Time Requirements

Listed below is an approximate breakdown of the time spent in getting the data for this thesis.

Construction and assembly of apparatus.....	30 hrs.
Preparation and conduction of test runs....	58 hrs.
Calculation of slopes.....	140 hrs.
Statistical analysis.....	<u>20 hrs.</u>
Total.....	296 hrs.

It is apparent that excessive time was required for the calculation of the slopes. Each slope calculation involved determining and recording the rectangular coordinates for a saw tooth graph and then by the method of least squares determining the slope of the line of best fit. This procedure, which took approximately 30 minutes per graph, is so tedious as to preclude the use of the equipment to gather large quantities of basic motion data. Halberstadt has indicated that the time spent for conversion of the raw data to slope values may be greatly reduced by the use of an IBM system containing an IBM Calculator, IBM Duplicating Summary Punch and an IBM punched card system⁹. It is felt that the work of any investigator, possessing sufficient mechanical ability to construct such an IBM system, would be a considerable contribution to the field of metabolism experimentation.

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Generalized Linear Models

Linear models are an important part of the

statistical toolbox for data analysis.

Formulation and analysis of regression models

Modeling and estimation of linear models

Classification of models

Statistical inference

Modeling

It is important to understand the role of

the linear models in the analysis of data.

Linear models are used to describe the relationship

between a response variable and one or more

predictor variables.

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